FIG 1.—HEADGATE, BEAR RIVER CANAL, UTAH.

FIG 2.—HEADWORKS, BEAR RIVER CANAL, UTAH.

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U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 104.

A. C. TRUE, Director.

U. S. Office of expt. stations

REPORT

OF

IRRIGATION INVESTIGATIONS FOR 1900

UNDER THE SUPERVISION OF

ELWOOD MEAD,

Expert in Charge of Irrigation Investigations.

INCLUDING REPORTS BY SPECIAL AGENTS AND OBSERVERS W. M. REED, W. H. CODE, A. J. McCLATCHIE, W. IRVING, J. M. WILSON, R. C. GEMMELL, G. L. SWENDSEN, O. V. P. STOUT, W. H. FAIRFIELD, D. W. ROSS, O. L. WALLER, S. FORTIER, AND J. C. NAGLE.

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1902.

OFFICE OF EXPERIMENT STATIONS.

A. C. TRUE, Ph. D., *Director.*
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IRRIGATION INVESTIGATIONS.

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FRANK BOND, *Agent and Expert.*

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., December 2, 1901.

Sir: I have the honor to transmit herewith a report of investigations on the methods of conserving, distributing, and using water in irrigation, made in 1900, under the supervision of Prof. Elwood Mead, expert in charge of irrigation investigations, and to recommend its publication as a bulletin of this Office.

It is believed that these investigations have a practical value to every interest which has to do with irrigated agriculture. A more thorough understanding of the duty of water and the conditions which influence it is required as a basis for planning the larger and costlier works which must be built in the future, to assist in framing of contracts for supplying water which will be in accord with the necessities of users, and to enable those charged with the division of streams to properly perform their duties. The sediment investigations are showing the amount and character of the deposit which irrigation water places on land, and furnish information needed by both investors and legislators to determine the influence of silt on the duration of storage works. The growing importance of irrigation in the humid portions of the country has required the extension of these investigations until they now practically embrace every section of the United States.

The studies of seepage and evaporation, of the cost of supplying water by pumping, and a number of other related subjects to which these investigations have been extended have been taken up in response to a general desire for information. The fact that irrigation is as yet to many an experiment renders it especially important that whatever is already known elsewhere should be placed before farmers rather than to leave each one to learn for himself by experience.

In these investigations the Office has enjoyed, as hitherto, the cooperation of a number of the State agricultural colleges and experiment stations, State engineers, and many individuals and corporations in the different localities where our operations have been conducted.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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REVIEW OF INVESTIGATIONS.

By Elwood Mead,

Irrigation Expert in Charge.

INTRODUCTION.

The pages which follow contain the results of one year's study of the problems which confront irrigators in conserving, distributing, and using water. The report of the investigation of the irrigation laws and institutions of the arid States will be found in Bulletin No. 100 of this Office, entitled "Irrigation Investigations in California," and in a bulletin on irrigation investigations in Utah, which will soon be ready for publication.

While the investigations made in 1900 follow the same general lines as those of the preceding year, a better equipment and the increasing skill and experience of those in charge permitted their extension in several important directions. The reports of the several experts and special agents indicate clearly the character of the work done and the nature of the results secured. The report of Mr. C. T. Johnston describes some of the methods and special apparatus employed. It is the purpose of this review to compare a few of the results of the two years' study, and point out the importance and enduring relation which this work has to the development of the agricultural resources of this country.

One of the leading objects of this investigation is to determine the duty of water. In order to do this it is necessary to deal with a wide range of climatic conditions, and to study the influence of different methods of application and the requirements of different crops. A knowledge of this subject is absolutely essential to the proper organization of this branch of agriculture. Farmers need an approximate knowledge of the duty of water in order to make intelligent contracts for their supply. It is needed by the engineers and investors in order to properly plan canals and reservoirs. Without this knowledge every important transaction in the construction of irrigation works or in the distribution of water therefrom is very largely dependent on individual judgment or conjecture. How far this may be mistaken is shown by the measurements of the past two years. Many works have been planned on the assumption that water enough to cover the land to a depth of 1 foot during the season would bring crops to maturity. The average depth of water used, measured at the head-

gate, was over 4 feet. There is no question that this amount can be reduced by improving the condition of canals and by more careful and expert distribution by farmers; and as soon as the study of present methods has been prosecuted far enough the effort to improve upon these methods will be begun. The first thing, however, is to understand what is taking place under the methods now employed.

In this connection the studies of seepage and evaporation have proven to be of especial value. The losses in distribution are more serious than has heretofore been estimated by writers on this subject or was realized by canal owners or managers. The studies of the amount and influence of sediment have also thrown light on some of the most perplexing problems with which the proprietors of reservoirs and ditches have to deal.

While these investigations are designed primarily to aid farmers already engaged in the reclamation of the arid lands in the West, they have a vital importance to the country at large. Should Congress in the near future, extend aid in some form in the construction of irrigation works of too great magnitude and cost for private enterprise, the works so built should be based on accurate knowledge of what is necessary to give them enduring value. In constructing reservoirs it is as necessary to know whether they will be filled in a few years by silt as to know that the dam rests on a solid foundation; and it is as desirable to provide some means for the removal of this sedimentary accumulation as it is to provide an adequate wasteway for floods. In planning diversion works it is as necessary to know how much water it takes to irrigate an acre of land as to know how much water is available for such irrigation. The work that the Office of Experiment Stations is doing in showing where and how water can be used to best advantage forms a complement to the work of other departments in showing where and how it can be secured.

The prosecution of these investigations has led to their extension into fields not anticipated at the outset. One of these is the study of the problems of irrigation in the humid regions of the United States. The growing interest in this subject throughout the East, and the extent to which irrigation is being resorted to, has made it necessary, or at least very desirable, that all the aid possible be extended to those who are dealing with this matter experimentally in order that they may avail themselves of what has already been learned elsewhere.

In order to answer the inquiries continually being received, it has been found necessary to study a number of affiliated subjects the relation of which to irrigation becomes apparent only with a thorough understanding of the situation. The subject of pumping will serve to illustrate this relation. In many parts of the West, and in a majority of instances in the East, pumping furnishes the most economical and readiest means of securing the needed water supply. Farmers desire to know what is being done elsewhere in order to avoid wasting money in repeating others' mistakes. Hence this investigation is called upon for information regarding the amount of water

required for a given acreage, the size of pump needed to furnish it, the cost of pumping for different depths, the kind of power best suited to particular circumstances, the expense of its operation, and, in general, any information which will determine whether or not irrigation under given conditions will pay. The commercial importance of these inquiries is very great. This is true of the humid as well as the arid States. During the last two years more money has been invested in pumping plants to furnish water for irrigation in the rice-growing districts of Louisiana and Texas than has been expended on similar projects in any State of the arid region.

The investigations into these questions were begun too late to form part of this report. They have been referred to here because they have constituted an important addition to the year's work, and will hereafter constitute a separate division of the investigations.

COMPARISON OF RESULTS.

DUTY OF WATER.

An examination of the reports of the different experts and special agents shows close agreements between the average rainfall and average duty of water in 1899 and 1900. These averages are based on measurements made in ten States and Territories, at stations which are scattered over a region which embraces about one-third of the United States.

	Feet.
In 1899 the average rainfall for the irrigation period was	0.44
In 1900 the average rainfall for the same period was	.45
The average depth of water applied to crops in 1899 was	4.35
The average depth of water applied in 1900 was	4.13

VALUE OF CROPS GROWN PER ACRE-FOOT OF WATER USED.

The reports of the value of crops grown by irrigation show that the returns from the use of an acre-foot of water in 1899 were considerably greater than in 1900. Excluding the statistics relating to citrus fruits and kindred products which have an exceptional value—

The average value of the crops matured for each acre-foot of water used in 1899 was	\$8.95
In 1900 the value of the crops grown with the use of a like volume of water was	5.94
And the average value of the crop produced by an acre-foot of water for the two years was	6.74

These figures are based on the measurements of water at the heads of canals and include the losses in transit. Measurements made at the borders of fields show a mean depth of water used of about half that where measurements were made at the heads of canals. It must be kept in mind in considering these figures that the crop values referred to are not for an acre of land, but for each acre-foot of water used. The average crop value in 1899 was nearly \$39 per acre. In 1900 it was a little less than \$25 per acre. Nor must these values be taken as indicating what can be realized from stored water, because,

in a majority of instances, reservoirs will be employed only to supplement the natural flow, the stored water being turned in when the natural flow is insufficient. In this way the use of the stored supply for a few weeks will often be of as much importance as all of the water used during the remainder of the season.

LOSSES BY SEEPAGE AND EVAPORATION.

The studies of evaporation and seepage have been extended in order to show more clearly the extent of the losses from canals due to their action and the nature of the measures to be taken to lessen them. Much interest is being manifested in these investigations by farmers and canal managers. Extensive losses from seepage injure canal companies by lessening the volume of water they can deliver, and they often injure farmers by the water finding its way to the surface where it is not needed. The following table shows the rate of loss per mile in the canals where the measurements were most carefully made.

Average losses by seepage and evaporation.

Canal.	Rate of loss per mile.
	Per cent.
West line of Bear River Canal, Utah	1.11
East Jordan Canal, Utah	3.84
Arizona and Consolidated canals, Arizona	.48
Logan and Richmond Canal, Utah, 1899	3.17
Logan and Richmond Canal, Utah, 1900	6.17
Logan, Hyde Park, and Smithfield Canal, Utah, 1899	3.85
Logan, Hyde Park, and Smithfield Canal, Utah, 1900	6.60
Canal No. 2, Wheatland, Wyo., July, 1900	1.00
Canal No. 2, Wheatland, Wyo., August, 1900	.29
West Gallatin Canal, Montana	.87
Farmers' Canal, Montana	1.65
Middle Creek Canal, Montana	1.85
Big Ditch, Montana	1.16
Republican Canal, Montana	2.53
Mean	2.47

The percentage of loss given is of the total volume carried. The average of the percentages shows a loss per mile of 2.47 per cent. If this were to remain uniform throughout the entire length of the ditch, it would mean that in 40 miles all the water turned into the headgate would disappear through the sides and bottom, leaving none to be distributed through surface laterals. This, however, does not often occur in practice. In this table the heavy losses in Utah canals make the average loss rather large. In canals which have been substantially built and which are in good condition the mean loss more nearly approaches those of the Wyoming and Montana canals. The information at hand does not warrant any deductions as to what part of this loss is due to seepage and what to evaporation, except that the losses from seepage are by far the heavier. Measurements made in 1899 showed that in cement-lined canals, where the only loss was from evaporation, it was comparatively insignificant. The measurements of evaporation show, however, that it is an important factor in the management of reser-

voirs. Experiments made at the University of Arizona show an average annual loss from canals and reservoirs for three years, 1892, 1893, and 1894, of 77.5 inches (p. 102). Experiments at Mesa, Ariz., from May 2 to November 12 show a loss of 47.41 inches (p. 103). On the station farm of the university at Reno the loss from May 4 to October 24 was 42.2 inches (p. 151). At Wheatland, Wyo., the losses by evaporation from a tank on land were found to be 66.4 inches, while those from a tank floating in a canal were 54.45 inches, or a mean of 60.4 inches (p. 208). The difference between the loss from a tank surrounded by land and another surrounded by water is of interest, and further measurements of this character will be made in the future. The largest loss from evaporation does not occur in canals, but in laterals and in distribution over the surface of fields. During the summer months water becomes heated in transit through canals and laterals, and when turned on the hot, dry surface of the fields, a large percentage of it goes up in the air. The losses from seepage must be looked for in the main canals, the losses from evaporation in the laterals and on the fields.

RELATION OF NEEDS OF CROPS AND FLOW OF STREAMS.

One of the valuable results of the studies of the duty of water will be the determination of the relative needs of crops during the different months of the irrigation period. By comparing the relative quantities of water used in the different months with the variations in the flow of streams which furnish the water supply farmers and canal owners can determine much more accurately than has heretofore been possible what percentage of the natural flow can be utilized by direct diversion and what percentage must be stored in order to render the whole run off available. In the following table the records of the flow of water in typical canals located in different arid States and Territories show with close approximation to the average practice the percentage of the total volume used in the different months of the irrigation season.

Relation between the amount of water used each month from a number of canals and the total seasonal discharge of the canals.

Canal.	Total seasonal discharge, 100 per cent.	Proportion of total discharge used in each month of the irrigation season.						
		April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Upper Canal, Utah	6,013.90	11	35	34	10	6	4	....
Sunnyside Canal, Washington	112,054.29	10	13	14	19	20	14	10
Pecos Flume, New Mexico	58,022.00	13	14	21	17	20	11	4
Wheatland No. 2, Wyoming	25,122.88	....	....	18	53	29	....	....
Orr Ditch, Nevada	20,348.66	13	15	19	18	17	14	4
Farm of A. F. Long, Idaho	400.90	3	11	20	31	26	9	....
Big Ditch, Tilden Ranch, Montana	46,995.42	....	5	31	28	21	15	....
Average	....	7	13	22.4	25	19.8	9.6	3

A comparison of these percentages with tables showing the run off of streams used in irrigation will show this interesting fact: That crops need large volumes of water in July, but streams during this month are as a rule far lower than in May or June. It will show that while nearly 20 per cent of the water used in irrigation is used in August, the August flow of streams will not average 10 per cent of the total discharge. The function of reservoirs is to bring these two percentages into harmony, to hold back the surplus water of the early part of the year to meet the larger demands of irrigators in the latter part.

RESULTS OF IRRIGATION IN HUMID REGIONS.

The investigations of irrigation in the humid regions of the United States have been extended to meet the constantly growing interest of this section. The report of Professor Voorhees on irrigation in New Jersey[1] was published in advance of this report in order to meet more promptly the inquiries of Eastern farmers. The report of Professor Stout on the duty of water under the Great Eastern Canal in Nebraska (p. 195) describes the results of irrigation in the humid portion, or at least the subhumid portion of the United States. This canal is situated between the ninety-seventh and ninety-eighth meridians, in a region where crops are usually grown by the aid of rainfall alone, and where the average annual rainfall for the last thirty years has been 27 inches. Nevertheless, since 1897 the area irrigated under this canal has approximately doubled each year. Seven times as many acres were irrigated in 1900 as in 1897, while the number of irrigators increased from five to sixty. In 1900 enough water was applied to 2,200 acres, in addition to that received from rain, to cover it to a depth of 14 inches. In no year since the canal was completed has the use of water proved injurious. On the contrary, it has been eminently profitable, the crops grown under irrigation having averaged 50 per cent larger than those grown without it.

PUMPING FOR IRRIGATION.

The cost and feasibility of providing a water supply by means of pumps has been studied to some extent during the past year and will receive more attention in future. Based on his investigations in Arizona, Mr. Code reports (p. 98) that on lands yielding large returns pumping to supply the deficiencies of the natural flow of streams is not only practicable but highly profitable where the lift does not exceed 60 feet. In the region embraced in Mr. Code's investigation, using wood costing $4 per cord as fuel and assuming a duty of 4 acre-feet of water to each acre irrigated, the expense of raising the entire volume required from a depth of 50 feet was found to be about $10 per acre. The investigations on Cache Creek, California,[2] show

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 87.
[2] U. S. Dept. Agr., Office of Experiment Stations Bul. 100, p. 183.

what can be done in pumping water for small, well-cultivated areas. A number of farmers along this stream raised water from 10 to 35 feet and irrigated their orchards and gardens at an average cost for the season of $5.25 per acre. On Fresno Slough, California, several electrical pumping plants have been installed at a cost of $8,000 each, which have irrigated land at an expense for operation of from 25 to 35 cents per acre.[1] The drought in southern California which has prevailed during recent years has led to an immense development of underground waters and an extensive use of pumps to bring it to the surface. The fact that this has paid is shown by the continued extension of this development.

SILT DETERMINATIONS.

The investigations of Prof. J. C. Nagle, of the Agricultural College of Texas, to determine the volume and fertilizing qualities of the silt carried in the rivers of the West and Southwest, show that the construction of reservoirs should always be preceded by a careful investigation of this subject. It is the purpose of this investigation to lend all the aid possible to the solution of the agricultural and engineering problems created by the accumulations of silt and sand in canals and reservoirs. It is as important in preparing the plans for many storage works that they should embrace means for removing these accumulations as to provide that the dam shall rest on a solid foundation or be of sufficient strength to withstand the pressure which is to come against it. A table, compiled from the results of Professor Nagle's measurements, is believed to have sufficient interest to warrant its insertion here.

Average percentages of silt carried by streams included in the investigations of Prof. J. C. Nagle.

Name of stream.	Date water samples were taken.	Average amount of silt carried.	Average amount after deducting 25 per cent for shrinkage.
		Per cent.	*Per cent.*
Brazos River, Texas	May, 1899, to November, 1900	1.09	0.81
Brazos River, Texas (estimated)	August, 1899, to October, 1900	1.28	.96
Rio Grande, Texas	June and July, 1900	.34	.25
Pecos River, New Mexico	July, 1900	.43	.33
Do	July to December, 1899	.15	.12
Laramie River, Wyoming	May to October, 1899	.013	.01
Salt River, Arizona	May to July, 1899	.18	.14
Wichita River, Texas (estimated)	February to September, 1900	1.17	.90
Wichita River, Texas	May, 1899, to September, 1900	1.34	1

The deduction of 25 per cent for shrinkage in the fourth column is based on a number of experiments which showed that samples left standing for a year lost about this proportion of their volume. The discussion of Professor Nagle is worthy of perusal by those who contemplate the construction of storage works in the southwest or who depend on the water supplies which such works furnish.

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 100, p. 313.

ACKNOWLEDGMENTS.

The interest and cooperation of farmers and canal companies throughout the arid region have been so general and cordial that it is impossible to make any acknowledgment except a general one of the courtesies and assistance extended to the experts and special agents engaged in this work. While not so directly concerned, the principal railway companies of the arid region have been most generous in supplying information wherever requested and in promoting the scope of this work in every way.

The discussion of Mr. Johnston gives the names of the special agents and experts with whom we have officially cooperated, but this does not include a number of institutions whose assistance in special investigations has been especially helpful. In this list belongs a number of State agricultural colleges, which have been conducting independent investigations along kindred lines and whose authorities have responded in the most generous manner to all requests for information. In this list of institutions are the State agricultural colleges of North Dakota, Colorado, and Oregon; the State universities of Wyoming, Utah, and California, and Stanford University, in California. The several State engineers have also worked with our experts and special agents in the collection of data, in enlisting the interest of farmers and ditch owners, and giving the widest possible extension to the measurements being made. The assistance rendered in our investigations in California by the California Water and Forest Association, the Sacramento Valley Development Association, and the Chamber of Commerce of Woodland have been acknowledged in the bulletin dealing with these investigations.

DISCUSSION OF INVESTIGATIONS.

By C. T. JOHNSTON,

Assistant in Irrigation Investigations.

The investigation of the use of water in irrigation for the season of 1900 has been carried on along the same general lines as that of 1899, the results of which are reported in United States Department of Agriculture, Office of Experiment Stations Bulletin 86.

No attempt has yet been made to regulate the volume of water supplied to the land. It has been considered best to determine the quantity used without restriction. Only such changes have been made in the design of measuring devices, the construction of registers, and the installation of the same as experience has shown to be desirable. The measuring flume has largely taken the place of the weir as a measuring device, and as its employment requires the use of a current meter that instrument has grown in importance.

EXTENSION OF INVESTIGATIONS.

Field operations have been extended as agents have been secured and advantages offered for carrying on the work. Many applications have been received from irrigators to carry on special investigations in their neighborhood, but it has been impossible to install new stations except where special opportunities were afforded. These conditions have been met with in the State of Washington, where Prof. O. L. Waller has made some investigations of the use of water at Prosser and Zillah. His work will be considerably extended during the season of 1901.

Work is now being carried on at the following stations from which no reports have yet been received:

State.	Location.	Observer.
South Carolina	Summerville	Dr. C. U. Shepard, in charge of tea (irrigation) culture.
Wisconsin	Madison	Prof. F. H. King, of the University of Wisconsin (Agricultural College).
Missouri	Columbia	Prof. H. J. Waters, of the University of Missouri (Agricultural College).
Louisiana	Crowley	Frank Bond, agent and expert, Irrigation Investigations, in charge of rice irrigation.
Texas	Raywood	

This bulletin contains papers from stations given in the table below, with the exception of the work carried on in New Jersey. The report of Prof. E. B. Voorhees, of the New Jersey Experiment Station, has been published separately.[1] It covers the work carried on during the season of 1899. The investigation in Nebraska has been changed somewhat, owing to special advantages being offered in the eastern part of the State. The locations of other investigations, as shown by a number of the reports, have been changed for similar reasons. The work of Prof. J. C. Nagle has covered a large field. In connection with the silt investigation in his charge he has visited the Rio Grande at El Paso, and a number of points along the Pecos River in southeastern New Mexico. His principal work, however, has been on the Wichita and Brazos rivers in Texas. These two streams are probably representative of Texas rivers, and the results he has obtained will largely apply to the water courses of Texas, New Mexico, and Arizona.

Investigations have been continued by the following agents at the places named:

Official stations for irrigation investigations and names of observers.

State.	Location.	Observer.
New Jersey	New Brunswick	Prof. E. B. Voorhees, director of the New Jersey Experiment Station.
Nebraska	Columbus	Prof. O. V. P. Stout, of University of Nebraska.
Montana	Bozeman	Prof. S. Fortier, director of the Montana Experiment Station.
Wyoming	Wheatland	C. T. Johnston, assistant, Irrigation Investigations.
Do	Laramie	W. H. Fairfield, of the Wyoming Experiment Station.
Texas	College Station	J. C. Nagle, of the Texas Experiment Station.
New Mexico[1]	Carlsbad	W. M. Reed, chief engineer Pecos Valley Irrigation Co.
Arizona	Phoenix	W. H. Code, chief engineer Consolidated Canal.
California	Riverside	W. Irving, chief engineer Gage Canal Company.
Utah	Logan	Prof. George L. Swendsen, of the Utah Experiment Station.
Do	Salt Lake City	R. C. Gemmell, State engineer, Utah.
Idaho	Boise	D. W. Ross, State engineer, Idaho.
Nevada	Reno	J. M. Wilson, agent and expert, Irrigation Investigations.
Washington	Zillah	O. L. Waller, of the Washington Agricultural College.

[1] Records of the duty of water at Aztec and East Las Vegas are also being furnished by the New Mexico Agricultural Experiment Station.

INSTRUMENTS USED.

WATER REGISTERS.

VALUE OF WATER-REGISTER RECORDS.

Since the field work under the direction of this investigation began the use of water registers has grown in favor. For many years inventors have striven to design an automatic regulating gate to furnish a constant discharge under a varying head. This has never been accomplished. A great many designs, judged superficially, should give

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 87.

accurate measurements. Some detail of the completed structure is always faulty, and for some reason is put out of use, and the "ditch rider" is again compelled to read the depth of water flowing over a weir or through a flume as often as his other duties permit. The water register simply takes the place of the ditch rider, only its work is more accurate and is continuous. It also gives an impartial record. If the user of the water and the party who furnishes the same are present when the register is installed and both are satisfied that the pen records the proper depth at that time, the week's record should be satisfactory to all concerned.

The water register used in this work can be kept locked and the records watched and the computations made by a disinterested party. The depth of water flowing over the weir or other measuring device can be checked whenever there is any doubt as to the accuracy of the record. The register sheets can be computed at the end of the irrigation season, and the volume of water corresponding to the recorded depths can be found in a few minutes. If the irrigation season covers a period of four months there are only 16 or 17 register sheets to be considered. It has been found to be more satisfactory to the company disposing of the water as well as to the irrigator to be informed of the volume of water furnished rather than to contract for the delivery of a definite number of cubic feet per second for an indefinite period and for neither one to know whether or not the specified volume was being delivered.

When the volume of water is measured as above described the irrigator knows exactly what he receives. It is surprising how long irrigators have paid for water regardless of whether they have received it. A large majority are satisfied with crude measuring devices, and until recently but little interest has been manifested toward keeping a continuous record of the volume of water supplied. If a man buys any other kind of property both parties in the transaction desire to have it carefully measured. The same men are willing to buy and sell water, one of the most valuable commodities, without knowing how much is or may be delivered.

The water register has other important uses. When placed at a gaging station on a river it furnishes a complete record of the depth of water flowing there. It can be used to record the depth of water evaporated from a tank, and is now employed to measure the water furnished by reservoirs along the Cache la Poudre River in Colorado. The reduction in the cost of instruments brought about during the past eighteen months will enable irrigators to employ them generally and bring about a better knowledge of the volume of water used and the volume necessary for the growth of various crops. The duties of the ditch rider or other person in charge of the regulation of headgates of laterals are greatly reduced by the use of water registers. If an irrigator raises the gates so that his supply of water is increased the

register will indicate it, and he must pay for this additional volume when he settles with the parties supplying the water. If he finds that he does not need as much water or does not need the volume supplied for as long a period as estimated, he can decrease or entirely stop the flow of the water allotted to him, and the register records this.

Water registers will doubtless become cheaper as their use extends. If this proves true it will be only a few years before they will be generally employed on large canals and the laterals diverting water from them. When State supervision has developed so that the rights of all are carefully guarded even the owners of small ditches will have to install weirs or measuring flumes and water registers. Colorado has already made provision for the use of registers by irrigators. The law has never been carried into effect, largely on account of the high price of instruments. Nearly all States where irrigation is of much

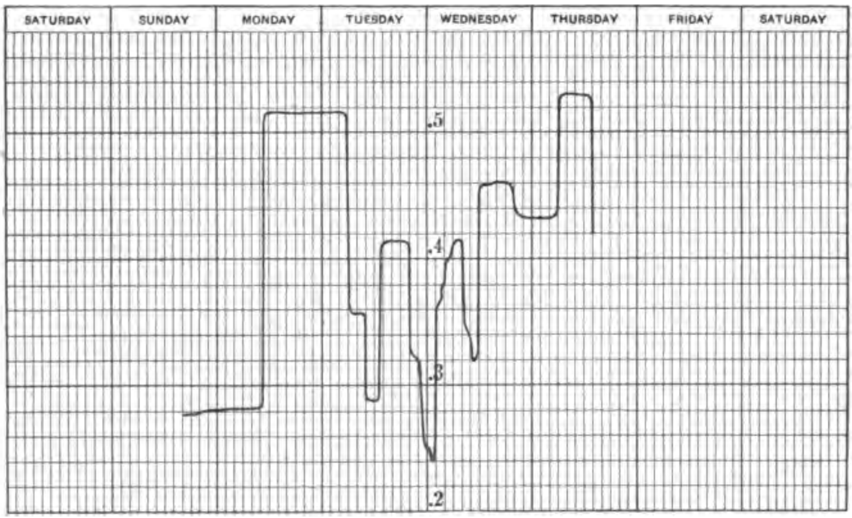
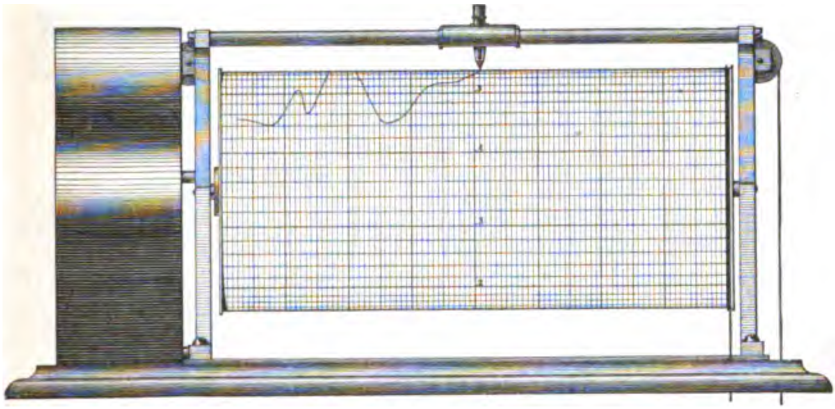


FIG. 1.—Diagram showing variations in depth over weir which was supposed to furnish a uniform supply.

importance require the installation of measuring boxes or weirs whenever the authorities deem it necessary. However, no attempt has yet been made to keep a continuous record of the water flowing through these devices. Without a continuous record but little is known of the volume used and nothing is known of the time when fluctuations in discharge occur. Water can be stolen and canal companies can deprive the irrigator of his share of the water without any record having been made or without the party injured being notified. When gaging stations on the natural streams are supplied with registers the available supply of water is always known, and this can be distributed in the most economical way when accurate means of measuring water are employed by the irrigators.

During the irrigation seasons of 1899 and 1900 several hundred

register sheets have been examined in this office. None of them shows that a constant depth of water passed through the measuring flume or over the weir from which the record is taken for more than a few minutes at a time. Many of the laterals where continuous records were kept were supposed to furnish a uniform discharge. That this has never been brought about the register sheets testify. Fig. 1 shows a register record taken from a lateral whose discharge was claimed to be uniform. That such a flow can not be obtained except under



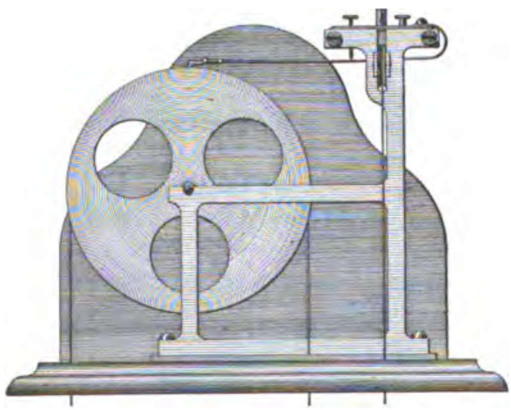


FIG. 2.—Design of water register manufactured for the Department.

unusual conditions can not be doubted. Nevertheless, canal companies sell a specified number of cubic feet per second to the irrigators under their systems, and contracts providing for the disposal of water under such conditions are often carried into effect with but little friction.

The design of new instruments. for recording the amount of water used in irrigation and the modification of those already in use so as to reduce their cost and increase their efficiency has been continued during the past year. In this work valuable aid has been rendered

by Messrs. W. & L. E. Gurley, of Troy, N. Y.; Mr. Julien P. Friez, of Baltimore, Md.; the A. Leitz Company, of San Francisco, Cal., and

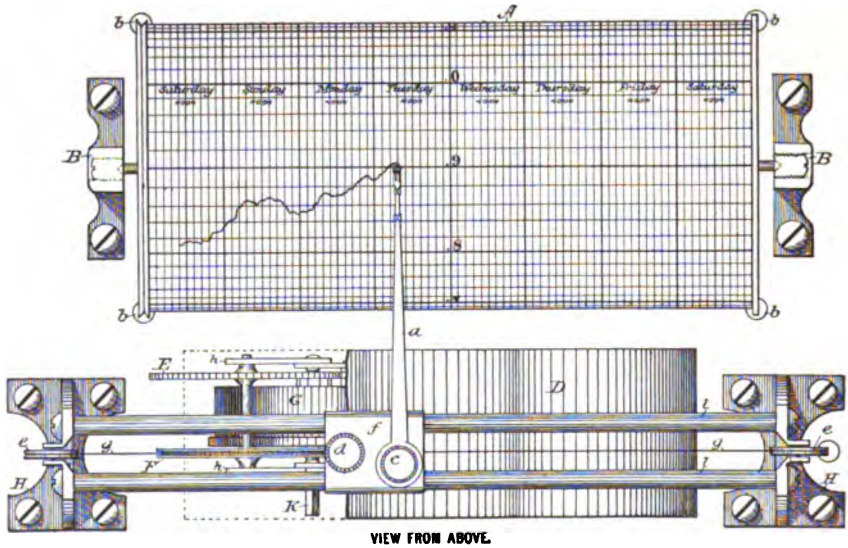


FIG. 3.—Water register manufactured for the Department (view from above).

the Modern Machine Works, of Denver, Colo. As a result of this study water registers of the latest approved design (figs. 2, 3, and 4)

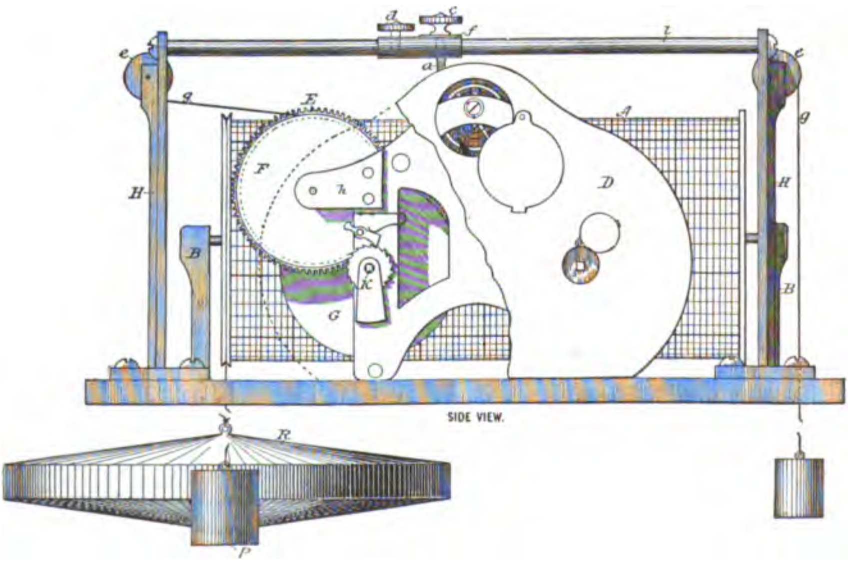


FIG. 4.—Water register manufactured for the Department (side view).

are now being furnished to irrigators at about one-half the cost of imported instruments.

INSTRUCTIONS FOR INSTALLING WATER REGISTERS.

The following instructions apply to water registers of nearly all kinds. The points touched upon are the most important ones which have been brought to the notice of the office through correspondence and conversation with observers in charge of the instruments and from the work at the testing station at Cheyenne.

(*a*) Before installing the water register the weir or measuring flume should be carefully constructed, and a platform and well for the instrument itself should be built. The well for the float should be connected with the water in the measuring flume or above the weir by a small pipe or a hole bored with a gimlet. The platform upon which the instrument rests should be horizontal and should be far enough above the water so that the weights will have plenty of room to move without touching the surface. It may be impossible to install the instrument high enough so that the counterweight for the float does not touch at times. If possible, however, this should be provided against. The weight which moves the pen carriage on the instruments of later design should in no case touch the water. The float and weights should be boxed in so that the wind will not affect the accuracy of the record.

(*b*) After this preliminary construction has been finished place the register on the foundation before the wires or cords running to the weights and the float and the counterweights are attached. With a lead pencil mark around the edge of the base so that the register can at any time be replaced in the same position. With a pencil or sharp-pointed instrument mark on the board the places where the holes must be bored for the cords or wires. The register can then be removed from the foundation and the holes bored.

(*c*) The circumference of the drums of all the instruments in general use is 1 foot. The register sheets are made to fit the different instruments whether the cylinders are 8 or 12 inches in length. After considerable experiment a paper has been found which takes the register ink well, and all stations supplied with instruments by the U. S. Department of Agriculture will be furnished with sheets of this quality. The ink is also furnished by the Department. It contains glycerine in its composition, which largely prevents evaporation. The presence of this fluid adds to the danger of the ink spreading on the paper before it dries. For this reason it is very desirable that the pen make a fine line.

(*d*) It will be found that the register sheets when applied to the drum do not exactly fit unless they are kept in a damp place. The sheets for two or three weeks or a month ahead might be kept under a dampened blotter or cloth until needed. The narrow margin should be trimmed to the printed lines. In case the pen does not travel over the lap in the register sheet as easily as it should, the paper at the lap

can be beveled with a sharp knife or rubbed with a dull instrument while the paste or mucilage is drying. The pen is filled by dipping a match or other small piece of wood into the ink bottle and allowing a drop to enter its cylinder. It seldom occurs that the pen will mark until the ink has been brought through the same by opening the nibs with a small knife blade or similar instrument. The pen is quite a delicate instrument, and great care should be taken not to bend it out of shape. Should this happen, the pen will have to be removed from the arm and the nibs be bent into position. Should the pen make a broad mark, it is generally an indication that the nibs are too far apart. To remedy this, remove the pen from the arm, insert a match in the cylinder of the pen, and with the thumb and finger or small pair of pliers bend the nibs toward each other. Remove the match and examine the points with a magnifying glass. It may be necessary to grind the points of the pen after they have been bent in this way in order that they may be made the same length and be smooth. Only the finest kind of oilstone or hone should be used for this purpose. The pressure of the pen on the paper should be no more than that produced by its own weight. This should be regulated by bending the arm of the pen.

(*e*) To begin a week's record place the pen on the register sheet at the time of day the record commences. The depth shown by the position of the pen on the register sheet should agree with the depth of water in the flume or over the crest of the weir. This latter adjustment can be made by slipping the cord or wire running over the drum in the direction necessary to correct the error.

(*f*) The register sheets are fastened to the drum by lapping one end over the other and applying a small quantity of library or similar paste. This paste should be applied under the printed edge, which should be lapped over the wide margin at the other end of the sheet. In removing the sheet at the end of a week's record care should be taken not to scratch or injure the drum. This can easily be avoided by taking a sharp knife and cutting the paste. The sheet is then removed without injury and the drum is at all times protected by a layer of the paper. The register should be visited each day during the first week it is installed. If it continues to run uniformly and give good results, it need not be watched so closely during the remainder of the season.

(*g*) The floats for a large number of the water registers are made of copper. They are circular, and are from 6 to 8 inches in diameter and 1 to 3 inches high. The top and bottom of the float are conical. To make the float steady in the water it is generally necessary to weight it either by pouring in fine shot or melted lead. The latter method is preferable, as the ballast does not easily shift. The counterweights are of lead, and they vary in size according to the use to which they are put.

REGISTER TESTING STATION.

While the water register is simple in design and construction, yet to secure reliable results considerable care must be exercised in installing instruments and in watching the record for the first few weeks. Registers have been sent from the manufacturer direct to the field without having been examined or tested. Very good results have been secured from many of these registers, but the best work has been done by those which have been set up at the testing station and carefully watched for a week or more.

The city of Cheyenne has permitted the office to install in its pump house, on Crow Creek, a station which offers all the conditions generally met with in the field. A tank has been constructed with automatic water connections, which cause continuous fluctuations in the height of the water surface. The details of the apparatus are shown in fig. 5. Three or four registers can be tested at once.

The gradual change in the design of water registers makes it necessary that each new part be thoroughly tested. Experiments must be made to prove whether a pen or pencil should be generally used. If a pen is used, the paper and ink must be of such quality that the latter will not spread and thus produce a broad, unsatisfactory line. It is often difficult to tell whether pens need sharpening or other adjustment before being sent into the field. The only way to determine this is to permit them to make a trial record. A great many facts have been learned by the tests made during the winter of 1900–1901. The relation of the size of the float and the weight of the counterweight have been determined. Tests have been made to find whether a cord or a wire is better for connecting the float and counterweight. Different kinds of pens have been used, and the flow of water has been adjusted so as to meet nearly all the conditions liable to be found in actual field work. While the test is being made to determine how the register can be changed to give the best results, the clockwork is regulated so that when the instrument is installed in the field there will be no difficulty in this direction.

WATER SAMPLE TRAP.

To enable those carrying on the silt investigation to collect the samples of water with greater ease, a water sample trap has been designed and constructed for their use. This trap is shown in the accompanying cut (fig. 6). It consists primarily of a brass cylinder 1 foot long and 3 inches in diameter. At each end is a door which revolves on a horizontal shaft. This axis runs the length of the cylinder, and the rapidity with which the door closes is regulated by a stiff steel spring which is coiled around the axis and fastened to the same by a sleeve furnished with a set screw. Near the top of the cylinder are two small rods, which are also furnished with springs, whose function is to

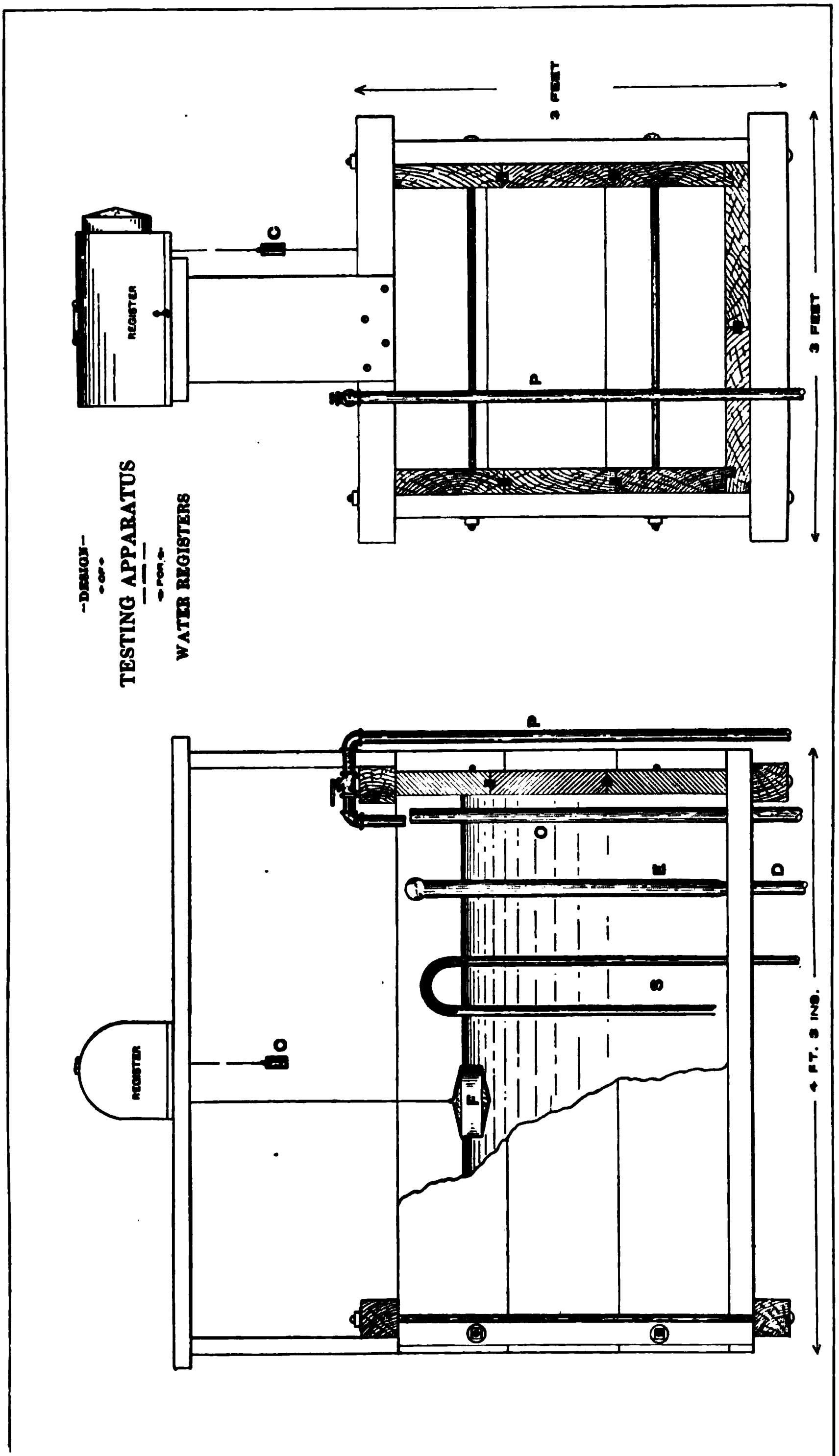


FIG. 5.—Design of testing apparatus for water registers.

move the ends of the rods beyond the plane on which the doors slide when they revolve. As soon as the doors are open, therefore, these rods hold them in that position until they are withdrawn. This result is accomplished by pulling two cords which are fastened to the rods. The trap is also furnished with a vane which keeps the cylinder parallel with the current. To use the trap it is suspended in the water at the desired depth, and when all is ready the doors are simultaneously closed by the device just described.

In silt measurements it is necessary that enough samples be collected to enable a mean value to be determined. The first is therefore

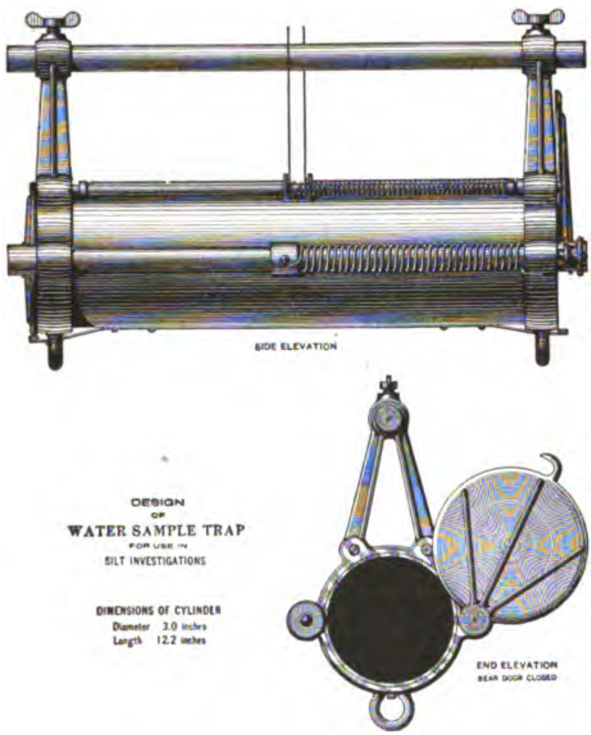


FIG. 6.—Design of water sample trap for use in silt investigations.

generally taken from the top and the work continued until the bottom is reached. As soon as the samples are taken, each is emptied into a jar of some kind and shipped to the station, where the analysis is made. The analysis not only determines the percentage of solid matter held in suspension, but also shows the nature and weight of each ingredient.

CURRENT METERS.

Electric current meters have been generally employed during the season of 1900. Current meters depend for their usefulness on the care with which they are rated, and as the rating of the best meters

changes somewhat with use, a station has been established at Cheyenne for this purpose.

RATING STATION.

Current-meter measurements depend largely for their accuracy on a determination of the relation between the rate of revolution of the wheel of the instrument and the velocity of flowing water in which it is held. It will be found that not only do meters of different designs vary in their rating, but that meters of like design seldom revolve at the same speed when immersed in currents having equal velocity. This variation is due to minute mechanical defects and differences which can not be overcome in construction, making it necessary that each meter have a separate rating. As meters are used their rating gradually changes. This change, of course, varies with the style of the meter, with the extent of use, and with the care exercised in handling the instrument.

A large part of the field work carried on by the irrigation investigations requires the use of the current meter. To make the results of the measurements trustworthy, a rating station has been established, where all meters are tested and accurately rated before being sent to observers in the field. They are again rated when returned to the Cheyenne office, for the purpose of noting whether any change has occurred during the period they have been in use.

Permission was obtained from the city authorities of Cheyenne to establish a rating station at the city reservoir on Crow Creek. The reservoir is a cement-lined excavation, rectangular in shape, 120 feet wide by 240 feet long. At the points marked A and B on the accompanying diagram (fig. 7) two pulleys were erected, each 10 feet in circumference. Passing around these pulleys and diagonally across the reservoir is an endless wire. A boat, the plan and elevation of which are also shown, is attached to the endless-belt wire, so that when the driving pulley at A is turned it is drawn diagonally across the reservoir. The current meter is attached to the forward end of the boat, in a vertical position with the meter wheel, 12 or 14 inches below the surface of the water.

Nearly all of the meters used by observers in the field are of the electric pattern, and the rating apparatus has been designed for this class of instrument. A heavy insulated wire is stretched from the supports of the two pulleys before referred to, on which a brass trolley connected with one of the terminals of the meter slides. Near the center of the wire the insulation has been removed for a distance of 200 feet. As soon as the trolley runs off of the insulation on to this wire the electric circuit is completed at each revolution of the meter wheel, ringing a bell at the driving pulley. The boat carrying the meter is drawn at any desired speed through the still water, and the time occupied in making the run is recorded, together with the number of revolutions of the meter wheel in that period. Knowing

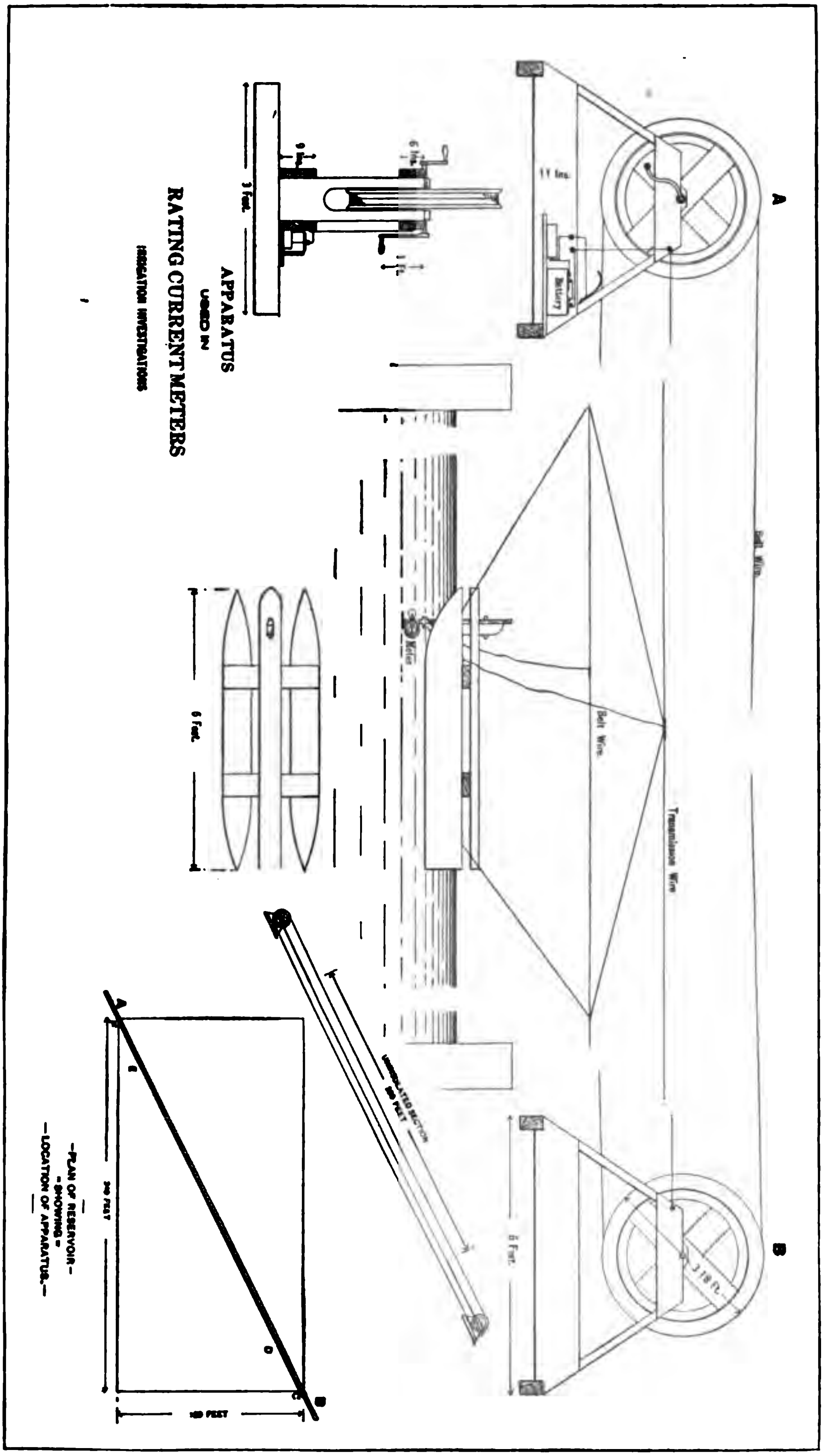


FIG. 7.—Apparatus used in rating current meters.

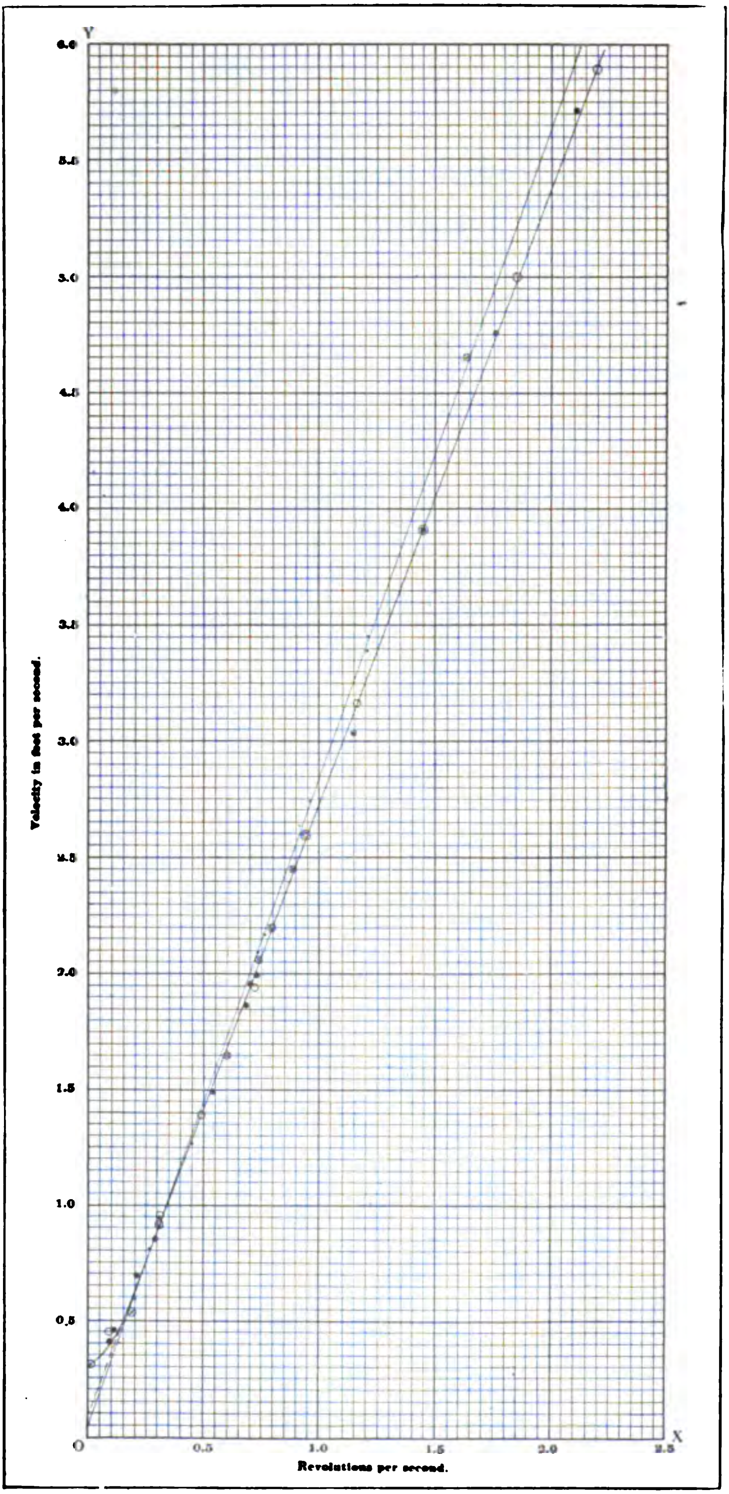


FIG. 8.—Rating curves of two meters used by the Department.

the length of the run to be 200 feet, the relation between the rate of revolution of the meter wheel and velocity of the boat can easily be computed. These observations having been obtained, an equation is found which represents a mean curve passing through as many of the points as possible. The notes can be reduced either graphically or analytically.

Graphical method.—From the observations taken at the rating station, the velocity of the meter or boat in feet per second and the corresponding number of revolutions per second made by the meter wheel are computed. These results are platted, the revolutions of the meter wheel per second as abscissæ and the velocity in feet per second as ordinates. Ordinarily the points thus platted lie on or near a straight line, which is to be located. This is conveniently done in the following manner: Through a point whose coordinates are an average of those already platted and conforming to all as nearly as possible a straight line is drawn. Fig. 8 shows the line obtained for two Department meters of the same pattern, Nos. 68 and 81. It indicates how differently the two meters behave in the same current. It will also be noticed that between velocities of 0.7 and 0.9 of a foot per second the curves are identical, but both above and below this section the variation is considerable.

The following comparative table shows this variation and indicates that below a speed of 0.25 revolution per second meter No. 81 runs the easier, while above this point the opposite is true.

Comparison of meters Nos. 68 and 81.

Revolutions per second.	Velocity in feet per second.	
	Meter No. 68.	Meter No. 81.
0.05	0.19	0.35
.25	.75	.75
.50	1.45	1.40
.75	2.14	2.06
1	2.84	2.72
1.25	3.54	3.38
1.50	4.24	4.04
2	5.63	5.36
2.50	7.03	6.68

There are two methods by which the rating table may be derived from the curve. One consists in reading from it direct the velocities per second corresponding to the number of revolutions per second; in the other, the rating table is derived from the equation of the curve. This being a straight line, its equation is of this form:

$$Y=MX+C,$$

in which Y and X are the variable quantities, viz, velocity of flow in feet per second, and revolutions of the meter wheel per second, respectively; M is the tangent of the angle which the platted line

makes with the axis of X, and C is the distance from the origin to the point at which this platted line crosses the axis of Y, otherwise known as the intercept on the axis of Y. This value of C is determined directly by measurement. The value of M is determined by calculation from average values of X and Y at various points on the curve. From this equation the rating table is computed, giving the velocity for each change of 0.05 revolution of the meter wheel per second. This graphical method is the one most commonly used by the office in the preparation of rating tables for the various current meters.

Analytical method.—This method is known as the rigid method, the equation being derived by mathematical calculation. The solution is sometimes aided by using the method of least squares. This process, however, is quite complicated, and it is extremely doubtful if the results obtained are more accurate than those obtained by the method just described.

As an example of the method pursued in deducting a rating equation and its subsequent use in making computations of the velocity of flowing water, a specific case will be cited, that of Department meter No. 81. It is an electric meter of recent pattern, and is especially adapted for the measurement of small streams, canals, and ditches. The first rating of this meter was made July 6, 1900. The observations taken at this date are shown in the upper division of the following table. The figures in the two columns on the left are the ones taken at the time of rating. The figures in the two columns at the right are derived from these.

Rating observations, Department meter No. 81.

RATED AT CHEYENNE, WYO., JULY 6, 1900.

Time of passage. (Seconds.)	Revolutions of meter.	Velocity of meter. (Feet per second.)	Revolutions of meter per second.
374	67	0.53	0.18
217	67	.92	.31
121	72	1.65	.60
91	72	2.20	.79
81.5	72	2.45	.88
43.5	71	4.65	1.64

RATED OCTOBER 4, 1900, AFTER BEING USED ONE SEASON AND BEFORE BEING CLEANED.

Time of passage. (Seconds.)	Revolutions of meter.	Velocity of meter. (Feet per second.)	Revolutions of meter per second.
490	42	0.41	0.09
434	49	.46	.11
288	60	.69	.21
234	67	.85	.29
134	72	1.49	.54
107	73	1.87	.68
102	71	1.96	.70
101	74	1.98	.73
66	75	3.03	1.14
51	74	3.92	1.45
42	74	4.76	1.76
35	74	5.71	2.11
33	74	6.06	2.24
31	76	6.45	2.45

Rating observations, Department meter No. 81—Continued.

RATED OCTOBER 4, 1900, AFTER BEING CLEANED.

Time of passage. (Seconds.)	Revolutions of meter.	Velocity of meter. (Feet per second.)	Revolutions of meter per second.
654	14	0.31	0.02
447	36	.45	.08
208	67	.96	.32
144	71	1.39	.49
103	74	1.94	.72
63	74	3.17	1.17
51	74	3.92	1.45
40	74	5	1.85
34	75	5.88	2.21

The distance traveled by the meter was in all cases 200 feet. The velocity with which the meter travels per second is the distance traveled divided by the time, or as in the first observation, 200÷374=.53 (foot per second). The number of revolutions of the meter wheel per second is found by dividing the total number of revolutions by the number of seconds consumed in making the trip, or as in the first observation, 67÷374=.18 (revolution per second). The velocity with which the meter travels and the number of revolutions of the meter wheel per second having been determined for each observation, the next step is the platting of these results on coordinate paper, with the velocities in feet per second as ordinates and with the number of revolutions of the meter wheel per second as abscissæ. Fig. 7 shows the rating curve for this meter.

The first division in the table gives the observations taken on July 6, while the meter was new, and before it had been used. These points are represented on the coordinate paper by crosses inclosed in small circles. The observations in the second division of the table were taken after the meter had been in use about two months and before it had been cleaned. These observations are represented on the coordinate paper by small circular dots. The observations in the third division of the table were taken after the meter had been cleaned. These points are represented on the coordinate paper by small circles. It will be noticed that the curve they assume is so nearly a straight line that no appreciable error is made in considering it one and deducing its equation as such. The only point at which the curve departs from a straight line is at its lower extremity.

In finding the equation of this line the method of deducing the general equation of a straight line is followed. This method has already been described. The value of C, known otherwise as the intercept on the axis of Y, in this case is found by producing the straight line until it intercepts the axis of Y. The distance between 0, the origin, and the point of intersection is found to represent 0.08 revolution per second. In finding the value of M, which is the tangent of the angle made by the straight line with the axis Y, the following method is pursued. The tangent of this angle is represented by

$$\frac{Y-C}{X}=M.$$

Substituting values for X and the corresponding values of Y, and knowing the value of C, a number of values of M are found. These vary slightly because of inaccuracy in the measurement of the values of X, Y, and C. In this case the value of M was found to be 2.64, so that, having determined both of the constants in the equation, the equation of the meter reads

$$Y=2.64X+0.08.$$

The rating table is prepared from this equation by substituting different values of X, or the number of revolutions per second, and solving for the corresponding values of Y. The intervals at which these values are determined vary with the accuracy required. The following is the rating table for Department meter No. 81, in which the computations were made for every 0.05 revolution per second from 0.05 to 2.50 revolutions per second.

Rating table, Department meter No. 81.

EQUATION: Y=2.64X+.08. RATED AT CHEYENNE, WYO., OCTOBER 4, 1900.

Revolutions per second.	Velocity per second.	Revolutions per second.	Velocity per second.
	Feet.		*Feet.*
0.05	0.35	1.30	3.51
.10	.43	1.35	3.64
.15	.52	1.40	3.78
.20	.63	1.45	3.91
.25	.75	1.50	4.04
.30	.87	1.55	4.17
.35	1.01	1.60	4.30
.40	1.14	1.65	4.44
.45	1.27	1.70	4.57
.50	1.40	1.75	4.70
.55	1.53	1.80	4.83
.60	1.66	1.85	4.96
.65	1.80	1.90	5.10
.70	1.93	1.95	5.23
.75	2.06	2	5.36
.80	2.19	2.05	5.49
.85	2.32	2.10	5.62
.90	2.46	2.15	5.76
.95	2.59	2.20	5.89
1	2.72	2.25	5.02
1.05	2.85	2.30	5.15
1.10	2.98	2.35	5.28
1.15	3.12	2.40	5.42
1.20	3.25	2.45	5.55
1.25	3.38	2.50	5.68

SEEPAGE INVESTIGATION.

When computed from the supply furnished at the headgate, the volume of water necessary for the growth of crops varies according to the character of the soil through which the canal and laterals run and the distance of the irrigated field from the point where the water is measured. On canals 40 or 50 miles long the quantity of water in them is greatly diminished near their lower extremities, and without the aid of seepage measurements only approximate results can be found. These results may be affected by water running in from lands bordering the canal; by seepage water entering the canal from the bottom or sides, or by heavy precipitation. The careless use of

water is one of the serious evils in any irrigated country where the water supply is at times in excess of the needs of the land. If a little water is good, more water is better, is a quite generally accepted doctrine. Water often runs in the canals a large part of the year for domestic purposes. While this may be a small stream, yet if not taken care of it will destroy large areas. Many places where the vegetation is beginning to show the evil effects of overirrigation can be drained. Others can be improved, if not entirely reclaimed, by exercising care in the irrigation of land directly above them.

The important feature of an investigation of seepage is to determine what volume is lost, where the loss occurs, and where the water reappears on the surface, either to be applied beneficially to other lands or to act as a detriment by producing marshes which have to be drained. Canal owners desire to know whether the loss is sufficient to warrant special precautions being taken to prevent it. California has in many places prevented excessive losses by cementing the canals. Utah is fast approaching the time when substantial dams and headgates must be maintained, when flumes and other structures must be made more permanent. Following this will come improvements in canals themselves. With the increase in the area devoted to fruit growing and the scarcity of water in the streams, every cubic foot that can be saved will have great value. With the present wasteful methods in vogue many canals lose one-half or one-fourth of their discharge, and hence have to be constructed large enough to furnish the lands under them with sufficient water and carry at their headgates in addition the volume lost.

Many cheap methods for reducing the volume lost from canals by seepage have been tried. Water carrying large quantities of fine silt will in time accomplish this. If sheep are driven across and along a canal immediately after the water has been turned out they will often puddle the surface of the ground thoroughly and in this way make the channel more impervious. By turning the water out of the canal at night and starting a large volume in early each morning a canal may be improved, as the water on entering always carries more or less silt which is deposited further along the canal each day. In western Texas, New Mexico, and Arizona the canals carry large percentages of silt in suspension, which makes an almost impervious coating on the bottom and sides of the channels. But little water is lost by seepage from such canals. In Colorado, Wyoming, Utah, and other Northern States the quantity of solid matter carried by the water is comparatively small and what is present is generally too coarse to aid in making the channels more impervious.

The channel of a canal in earth follows the dimensions of its theoretical cross section only approximately. After it has been used for some time it gradually adapts itself to the currents caused by accidental obstructions or changes in the direction of the line of the canal. With each fluctuation in the discharge of the canal the cur-

rents are modified and material at various points shifts to accommodate new conditions. This constant alteration in the channel prevents the bed of the canal from thoroughly silting unless the water carries a large percentage of fine solid matter in suspension.

The extent of seepage also varies with the volume of water flowing in the canal. While a large volume has a greater velocity and hence a smaller percentage should be lost in transit, yet this increased velocity may cause sufficient change in the channel to overcome the saving otherwise brought about.

Some striking examples have recently come to the writer's notice, showing the rapidity of percolation through sand and gravel. At Garland, Box Elder County, Utah, one farmer settled before the present Bear River Canal was constructed. He was informed that it was impossible to reach water at any reasonable depth and, hence, during the first two or three years of his residence, he hauled all the water used for domestic purposes from a spring two or three miles distant. Finally, disregarding all warnings, he began the digging of a well. He passed through 1 foot of black soil, 7 feet of white clay, 12 feet of red clay, 15 feet of loose gravel, 15 feet of clay in which was a foot of black loam, and then into 5 feet of loose gravel. When the first stratum of 15 feet of loose gravel was encountered he was compelled to crib the well to prevent its caving. When the second stratum of the same material was reached, he found it would have to be cribbed, but to proceed with the work the crib would have to be constructed in the well, as a second crib could not be lowered inside of the first. Work was accordingly stopped and nothing more was attempted along this line until after the canal reached his place. It passes 165 feet to the west and a few feet above the level of the ground at the well. The day after water reached his place the shaft began to fill with water. It came through the upper layer of gravel and within twenty-four hours the well filled to within 20 feet of the surface of the ground. The well was used for a time, but owing to its depth it had to be abandoned and a new one dug about 50 feet from the canal; this one reaches only the first stratum of gravel, where an abundant supply of water is found.

There are four operations connected with the work of measuring water lost by seepage. The first of these is to determine the volume of water supplied the canal at its headgate. The second is to locate all laterals and measure their discharge. The third is to measure the discharge of the canal at its terminus and wherever the formation changes or where indications would lead one to believe that the rate of loss varies. The fourth consists of carrying on simultaneously with the other work a record of the evaporation from the surface of the water.

While the measurements are being carried on the volume furnished the canal should be kept uniform. The time of the year should be selected when the discharge of the laterals will not need to be changed

and when the weather will favor accurate measurements. The latter condition would demand that the measurements be made when the wind has a small velocity, and when the weather is settled so that the rate of evaporation will be uniform during the period covered by the work. The measurements should be also made at a season of the year when the river is normal in its discharge, so that the water will be as free as possible from silt or floating material. After the measurements have all been made and the gagings have been computed the loss by seepage from any part of the canal, or from the whole, can be found by subtracting from the volume at the head of the canal or of the section the sum of the discharge of all the laterals between the points chosen and the discharge of the canal at the lower end of the section under consideration. The volume lost by evaporation is determined by finding the area of the surface of the water in the canal and applying the results obtained from the evaporation tank. When this is subtracted from the total loss, that due to seepage alone is found. This correction is always quite small and it can be disregarded in most cases.

In making the gagings only the best instruments should be used, and they should be kept in first-class condition. The meter should be rated prior to the commencement of the work and immediately after it has been concluded. Should opportunity occur during the field work the measurements should be checked by the results obtained from weir measurements.

Before making a gaging of a canal the channel should be examined and a portion of the same selected where the cross section is regular and where the canal is straight and uniform for 300 feet above and for some distance below. The material forming the bottom and sides of the canal should be stable, and the water lines well defined on each bank. As the work proceeds from the headgate down the canal, the care exercised in making the measurements should be maintained and, if possible, greater precautions should be taken in making the discharge measurements. With current meter measurements it is easier to gage a comparatively large volume of water than a small one with the same percentage of accuracy. In a canal 40 feet wide and 4 feet deep the depth is often measured at each foot across the section and the water measurements made as often. A ditch 5 feet wide and 1 foot deep could not be divided into as many sections, yet to secure the same percentage of accuracy this should be done.

Many requests have been received during the past two years for an extension of the seepage investigation. In response to this demand a large number of the agents making a study of the use of water in the various States have extended their work so as to include such measurements. The loss of water from canals has been found to be a serious feature in many localities, and canal companies will doubtless make extensive improvements in the channels of their ditches and laterals where the saving will pay for the cost of repairs. Some

measurements were made last year by the writer in Utah which are not connected in any way with the general investigation regarding the use of water in irrigation. A description of the canal systems where this work is carried on and the general results secured will be given in the following pages.

SEEPAGE MEASUREMENTS ON BEAR RIVER CANAL, UTAH.

The headgate of the Bear River Canal is located in Bear River Canyon, some 8 miles northeast of Collinston, Utah. The first 2 miles of the channel is in solid rock. A part of this is cemented, having a masonry retaining wall for the lower bank. Portions of it are in loose rock and in some places wooden flumes carry the water over the more porous material. The loss in this section of the canal is excessive. If it were not that the canal always supplies more water than is demanded by the area so far brought under cultivation, the channel would have already been repaired in such a way as to carry the water more economically. Large streams of water run through the loose rock and flow into the river in many places. Where flumes have been put in it has been difficult to make the wings and apron at the end connect with the rock sufficiently well to prevent large quantities of water from escaping.

From the canyon the canal has a southerly course along a steep hillside for several miles. It needs only a journey along the canal to see the effects of the seepage water. Flumes have been put in where hillsides have slid away and left chasms intersecting the line of the canal. In one place 40,000 or 50,000 cubic yards of saturated earth moved down the hillside and into Bear River, where it destroyed the headworks of a small ditch, including a dam and an irrigation wheel. To recompense the owners of the property for its loss the Bear River Canal Company permits them to use water from the canal at a small annual charge. At another place the hillside moved away and an immense ravine has been washed below the canal line. A flume nearly 150 feet long has been built to carry water across this ravine.

After the canal leaves the bluffs along the river and enters the agricultural land to the west the effect of seepage is more difficult to see, but that water escapes in large quantities can not be doubted. The section of the canal where the least loss occurs is probably that between the Corinne division gates and the Malad Flume. The channel of the canal is deep and the material is quite fine. However, the small tributaries of the Malad River, which reach out to the east in the vicinity of Fielding, show that either there is some return seepage water appearing in them or that the irrigators on the land intervening between these streams and the canal are careless in the use of water. Swamps and marshes appear along these streams and along the narrow bottoms of Malad River. Water runs away from these places constantly, and the borders of the swamps are extending in all directions. Malad River is very tortuous, and runs between vertical banks some 3 or 4

feet high. Springs have started near the surface of the water from these banks and also from the steep bluffs above them.

Evidences of return seepage water show along Bear River east of Fielding. Landslides have occurred there over a mile from the line of the canal. But few irrigated countries have a more porous subsoil than lower Bear River Valley. As soon as the water reaches the gravel it runs in all directions and fills it as fast as a supply is afforded. Between Garland and Roweville the canal runs around a rocky point. Near the extremity of this point Salt Creek has its source and to its ordinary flow is added that discharged by a wasteway in the canal. Salt Creek has a deep channel similar to that of Malad River, only that it is narrower. Numerous springs form its source of supply, and originally they were the only feeders for the creek. Since the canal has been in operation the springs have increased in size, and with the water coming through the wastegate Salt Creek yearly adds to the extent of marsh lands south of Roweville. This swamp existed prior to the construction of the canal. Since that time its borders have extended, and the day is not far distant when it will have to be drained into Great Salt Lake. There are but few localities where greater care must be exercised in the application of water to prevent waste and the ensuing destruction of the land. The lands under the Bear River Canal will ultimately be devoted almost entirely to fruit growing. When this has been brought about the value of the produce of an acre will largely increase.

Seepage measurements were carried on along the upper 22 miles of this canal during August, 1900. The actual work was begun at noon on August 6 and concluded at noon on August 8. The measurements began at Roweville and ended at the headgate, both of which points are shown in fig. 9. Before the measurements were begun a water register was installed at a flume near the headgate and the water was maintained at practically the same stage during the progress of the work. The ditch riders who regulate the flow of water in the main canal and distribute it to the various laterals aided the work materially by keeping the volume diverted from the canal uniform. Work was carried on as rapidly as possible, so as not to inconvenience the irrigators by holding the water at the same stage for a considerable time. When the headgate was reached it was found that the canal there carried 319.27 cubic feet of water per second. Immediately below the headgate is a flume which affords an unusually good section for the accurate measurements of the water carried by the canal. The velocity of the water there is swift, yet the current is quite uniform and free from eddies. The table which follows shows the results of the seepage measurements and some deductions therefrom. The table begins with the discharge of the canal at the headgate. It is believed that the measurements were sufficiently accurate and the discharge was maintained nearly enough constant to permit these approximations to be made.

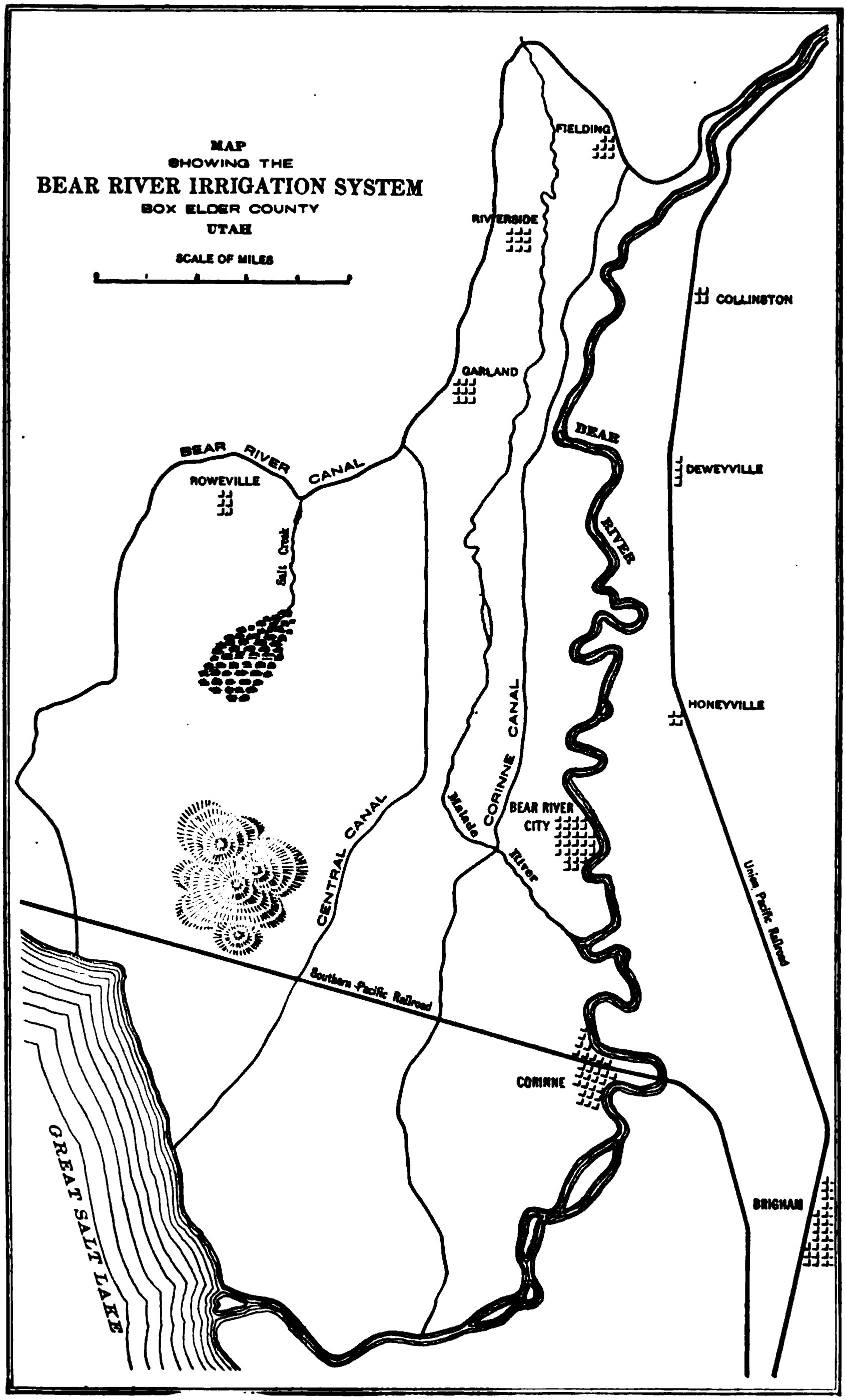


FIG. 9.—Map showing the Bear River irrigation system.

Results of seepage measurements in the upper 22 miles of the west line of Bear River Canal.

Place of measurement of canal.		Distance between stations.	Discharge, upper station.	Diversions between stations.		Discharge, lower station.	Loss.		
Upper station.	Lower station.			Lateral.	Discharge.		Quantity.	Percentage.	Per mile.
		Miles.	*Cu. ft. per sec.*		*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*	*Cu. ft. per sec.*
Headgate	Flume No. 3	2	319.27			287.27	32	10	16
Flume No. 3	Flume No. 9	½	287.37			285.21	2.06	.7	8.24
Flume No. 9	Flume No. 11	1½	285.21			284.45	.76	.3	.43
Flume No. 11	Above Corinne Lateral	1	284.45	Wheeler's Pipe Line	2.92	276.51	5.02	1.7	5.02
Above Corinne Lateral	Malad Flume	3½	276.51	Corinne Lateral	132.11	144.63	[1]—3.08	[1]—1.1	[1]—.88
				Lateral No. 1	.43				
				Lateral No. 5	2.28				
				Lateral No. 10	.16				
Malad Flume	Above Pitts's Bridge	4½	144.63			138.49	6.14	4.2	1.37
Above Pitts's Bridge	Bridge near Lateral No. 62	1½	138.49	Lateral No. 60	.19	126.27	12.014	.9	8.01
				Lateral No. 62	.016				
Bridge near Lateral No. 62	Manning's Bridge	1½	126.27	Lateral No. 65	.02	118.59	4.83	3.8	3.22
				Lateral No. 75	.51				
				Lateral No. 85	2.32				
Manning's Bridge	Bridge above Lateral No. 125	3	118.59	Lateral No. 90	1.36	93.39	3.31	2.7	1.10
				Lateral No. 95	1.50				
				Lateral No. 100	1.05				
				Lateral No. 104	2.53				
				Central Lateral	15.45				
Bridge above Lateral No. 125	At Roweville	3	93.39	Lateral No. 125	5.40	37.31	15.01	1.6	5
				Lateral No. 130	.38				
				Wasteway Salt Creek	31.54				
				Lateral No. 150	3.75				
	Total	22			203.906		78.064		
	Average loss per mile								3.54

[1] Gain.

In fig. 10 the width of the hatched portion at any point represents the discharge of the canal at that point. The reductions in the width of the hatched area on the upper side represent diversions; those on the lower side represent losses from seepage and evaporation.

It will be noticed that the loss in the first 2 miles was 32 cubic feet per second, or 10 per cent of the discharge of the canal at the headgate. This loss was anticipated, and it would not have been surprising had it been much greater. Since these measurements were made this portion of the canal has been greatly improved by the construction of masonry retaining walls and other works along it. There is probably no loss along that section of the canal between the point where the Corinne Lateral diverges and the Malad Flume. The measurements show a gain of 3.08 cubic feet per second. This is doubtless an inaccuracy in the measurements, and rather indicates that there was but little loss in transit. Except in the section immediately below the headgate more water was lost in the vicinity of Garland than at any other place along the line as far down as Roweville. Just above Garland the loss was over 8 cubic feet per second per mile. The surface indications would not lead one to believe that the loss there should differ greatly from other sections of the canal, but, as stated before, the land in the immediate vicinity of Garland is underlaid by porous gravel, through which the water runs rapidly as soon as it is reached. The total volume taken into the canal at the headgate was 319.27 cubic feet per second; the volume diverted by the laterals was 203.9 cubic feet per second. The total loss was 78.06 cubic feet per second. The average loss per mile was 3.54 cubic feet per second, and the total loss was 24.4 per cent of the water furnished at the headgate.

With the construction of the eastern branch of the Bear River Canal and the further use of water under the western line, Bear River will be taxed to its limit to furnish sufficient water. Under these conditions the value of water will be so increased that it will pay to save every cubic foot of it. The canyon section will have to be cemented and all flumes will be made as nearly water-tight as construction will permit. It may be that some of the line below the Malad Flume will be treated in such a manner as to make the channel practically impervious. But little water escapes through or around the end of structures along the canal below the canyon. The Malad Flume is one of the highest aqueducts and is the first one to be constructed of steel. Plate II, fig. 2, shows the steel work from below. The columns supporting the flume proper are 95 feet high and rest on concrete caissons. The structure as a whole is a monument of irrigation engineering and is a model of economy in the transportation of water.

There are no canals in the West which offer a better field for seepage measurements than those in the Bear River system. There is no place where precautions for preventing waste will have to be taken at an earlier date than under that system.

FIG. 1.—CHECK IN BEAR RIVER CANAL.

FIG. 2.—MALAD FLUME, BEAR RIVER CANAL.

FIG. 1.—CENTRAL LATERAL GATE, BEAR RIVER CANAL.

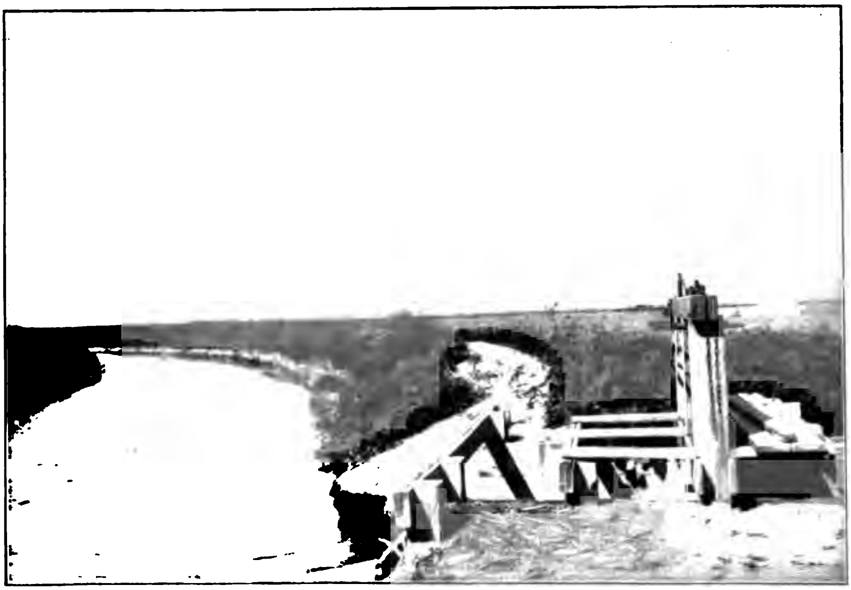


FIG. 2.—BEAR RIVER CANAL AND CENTRAL LATERAL GATE.

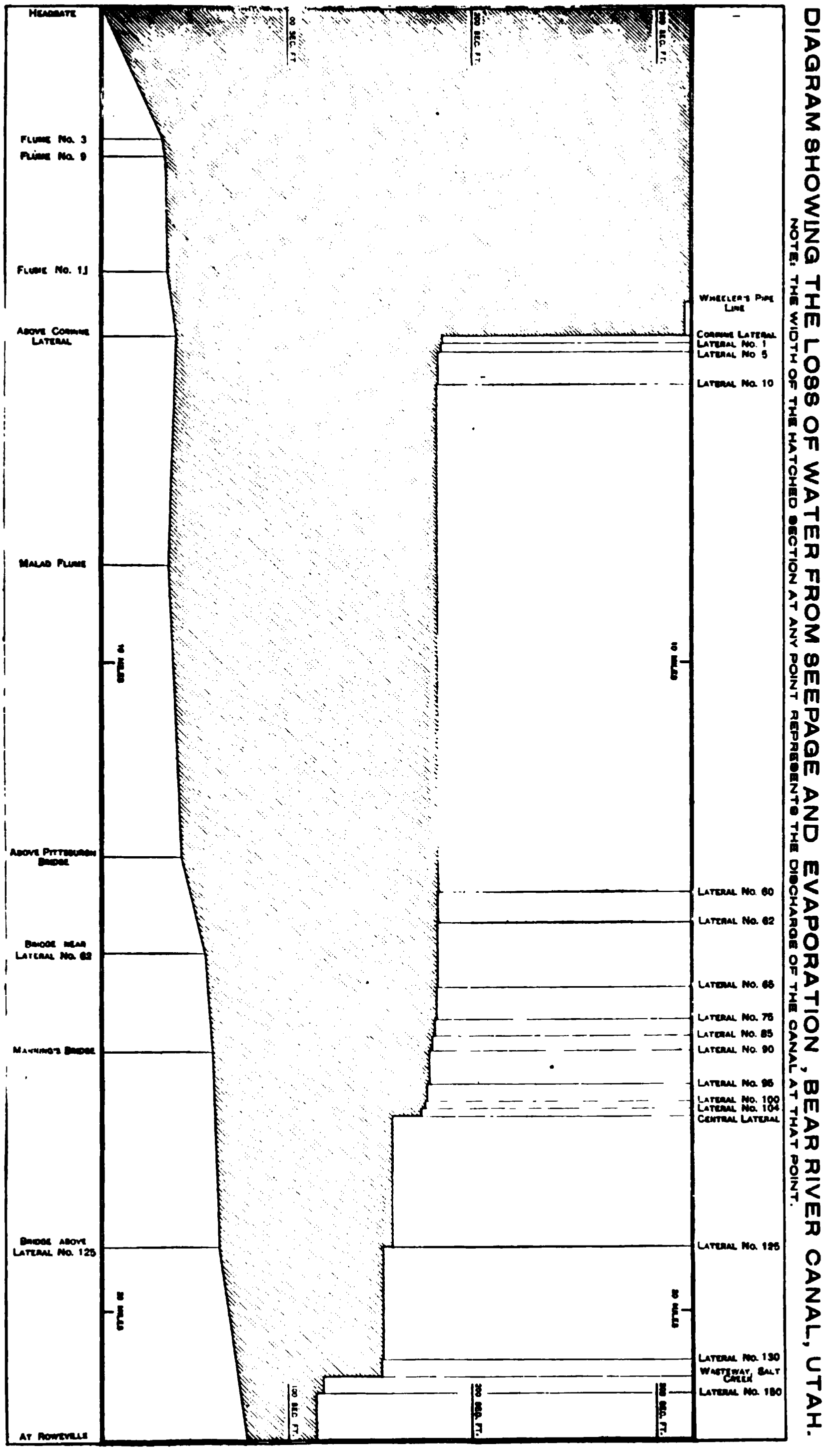


Fig. 10.—Diagram showing the loss of water from seepage and evaporation, Bear River Canal.

SEEPAGE MEASUREMENTS ON EAST JORDAN CANAL, UTAH.

On August 11, 1901, seepage measurements were made on the upper 9½ miles of the East Jordan Canal. The headgate of this canal is near the southern end of the Jordan Narrows and only a few miles from the northern extremity of Utah Lake. The canal traverses a steep hillside for over 3 miles below the headgate. The material along this portion of the canal is quite coarse and the loss due to seepage is excessive. After leaving the hillside the loss is quite small. The following table gives the results of the measurements made.

Results of seepage measurements in the upper 9½ miles of the East Jordan Canal, Utah, August 11, 1900.

Place of measurement of canal.		Distance between stations.	Discharge, upper station.	Diversions between stations.		Discharge, lower station.	Loss.		
Upper station.	Lower station.			Lateral.	Discharge.		Quantity.	Percentage.	Per mile.
		Miles.	Cu. ft. per sec.		Cu. ft. per sec.	Cubic feet per second.	Cubic feet per second.		Cubic feet per second.
Headgate	Bridge No. 1	1	42.46			37.70	4.76	11.21	4.76
Bridge No. 1	Power plant	1½	37.70			36	1.70	4.51	1.10
Power plant	Three-fourths mile below power plant.	¾	36	Lateral No. 1	1.22	34.49	.29	.81	.38
Three-fourths mile below power plant.	1 mile below power plant	¼	34.49			32.30	2.19	6.35	8.76
1 mile below power plant	1½ miles below power plant	½	32.30			29.93	2.37	7.34	4.74
1½ miles below power plant	Bridge No. 2	1	29.93			27.33	2.60	8.70	2.60
Bridge No. 2	Draper	3	27.33	Lateral No. 2	.94	16.44	.22	.80	.07
				Lateral No. 3	.24				
				Lateral No. 4	.66				
				Lateral No. 5	2.18				
				Lateral No. 6	.72				
				Lateral No. 7	.43				
				Lateral No. 8	2.33				
				Lateral No. 9	3.17				
Draper	Near Oregon Short Line Rwy	1½	16.44	Lateral No. 10	3.30	9.86	1.83	11.13	1.22
				Lateral No. 11	1.45				
	Total	9½			16.64		15.96		
	Average loss per mile								1.77

The canal received 42.46 cubic feet of water per second at its headgate on that date. One mile below the headgate its discharge was found to be 37.7 cubic feet per second, or a loss of 4.76 cubic feet per second. This rate of loss diminished in the next mile and increased rapidly in the neighborhood of the power plant, where it reached 8.7 cubic feet per second per mile. The summary at the bottom of the table shows that the laterals diverted 16.64 cubic feet of water per second from the canal, and 15.96 cubic feet of water per second was lost through seepage and evaporation. This is 37.58 per cent of the discharge furnished the canal at its headgate. The average loss per mile is 1.77 cubic feet per second. On the same day discharge measurements were made on the City Canal, which crosses Jordan River at the power plant and runs along parallel with the East Jordan Canal for some distance. It was anticipated that this canal would show a slight increase in its discharge, owing to the water from the East Jordan Canal returning therein. However, it was found that there was a gradual loss of water from it. At the power plant it carried 37.23 cubic feet per second. Three miles below it carried 29.03 cubic feet per second; 4 miles below it carried 27.76 cubic feet per second, and 5½ miles below it carried 25.57 cubic feet per second. While the City Canal may receive some water from the East Jordan Canal nearer Salt Lake City, it would seem that it should receive such a supply where the greatest loss occurs from the upper canal.

The following table brings together the results of the measurements made by all observers during the past season:

Losses by seepage and evaporation.

Canal.	Length.	Loss in part of canal measured.	Loss per mile.
	Miles.	*Per cent.*	*Per cent.*
Pecos Canal		[1] 57	
Salt River canals (estimated)		20	
Utah:			
Bear River Canal	22	24.40	1.11
East Jordan Canal	9.5	37.58	1.71
Logan and Richmond	9.2	20.96	2.28
Logan, Hyde Park, and Smithfield	8.37	22.13	2.64
Canal No. 2, Wheatland	13.67	12.82	.93
	17	17.01	1
Montana:			
West Gallatin Irrigation Canal	38.75	33.27	.89
Farmers' Canal	10.75	17.72	1.65
Middle Creek Canal	8.5	15.70	1.83
Big Ditch	22	25.56	1.16

[1] Difference between flow in Pecos Flume and water delivered to consumer.

DUTY OF WATER.

The results obtained during the season of 1900 show that a great many factors enter into the determination of the volume of water used per acre. On the Hagerman farm, at Carlsbad, N. Mex., a depth of water of 14.43 feet was used. The volume is not as excessive as the figures would seem to indicate when the following facts are considered. The irrigation season is long. The soil is very porous and has a heavy slope. The ground is shaded but little from the rays of the sun, and evaporation from the plants and from the surface of the fields is excessive. In addition to these factors the water is distributed by inexperienced irrigators. If the same volume had been applied to the lands under the canal on the opposite side of the river serious results would have followed. A farm furnished with a levee around its lower border would have been a reservoir at the end of the season and would probably have contained from 8 to 10 feet of water in depth.

The results for the season have been divided into three classes. The first is the general duty of water obtained from the measurement of main canals. The second is the duty obtained from the measurements of laterals at the margins of the farms where care has been taken in the distribution of water. The third class includes all the results obtained from the measurement of laterals where large quantities of water are needed, or where a careless or wasteful use has been permitted. These will be taken up in order and briefly discussed.

DUTY OF WATER OBTAINED FROM THE MEASUREMENTS OF DISCHARGE OF MAIN CANALS.

All of the canals which were included in the investigation during 1900 are given in the following table, with the exception of the Gage Canal in California. As this canal is cement lined, but little water is lost in transit, except by evaporation, and the measurements are practically the same as though they were made on a field lateral. It will be noticed that the table contains a number of figures which would indicate a high duty of water. The most striking in this particular are the depths to which the land was covered under the Big Ditch in Montana, the Great Eastern Canal in Nebraska, and the Middle Creek Ditch in Montana. The depths to which the land is covered during the season under these three canals were 1.88, 1.78, and 1.9 feet, respectively. Such figures as these indicate unusual care in the distribution of water, since the water supply was ample. The Sunnyside Canal in Washington represents an extravagant use of water. That the figures given for 1900 are not exceptional is

proven by measurements made in 1899, which are included in the table which follows:

Duty of water when losses in main canal are included.

Name of canal.	Length of irrigation season.	1899. Rainfall.	1899. Depth of irrigation.	1900. Rainfall.	1900. Depth of irrigation.
		Foot.	*Feet.*	*Foot.*	*Feet.*
Pecos Canal, New Mexico	March-October	0.31	6.61	1	6.99
Mesa Canal, Arizona	Entire year	.39	3.81	.27	2.35
Maricopa and Salt canals, Arizona	do			.37	2.45
Tempe Canal, Arizona	do			.27	2.88
Utah Canal, Arizona	do			.27	2.49
Butler Ditch, Utah	April-September	.49	6.24	.49	5.18
Brown & Sanford Ditch, Utah	do	.49	5.32	.49	4.08
Upper Canal, Utah	do	.49	6.30	.49	3.92
Tanner Ditch, Utah	do			.49	3.63
Green Ditch, Utah	do	.49	4.52	.49	6.14
Farr & Harper Ditch, Utah	do			.49	5.77
Lower Canal, Utah	do	.49	2.83	.49	3.08
Big Ditch, Utah	do	.49	3.00	.49	2.86
Logan and Richmond Canal, Utah	June-September	.27	3.27	.20	4.82
Logan, Hyde Park, and Smithfield Canal, Utah.	do			.20	3.94
Amity Canal, Colorado	March-September	.91	4.92		
Rust Lateral, Idaho	May-September	.22	5.06		
Prosser Canal, Washington	April-October			.26	3.04
Sunnyside Canal, Washington	do			.28	10.24
Big Ditch, Montana	May-September			.45	1.88
Middle Creek Ditch, Montana	June-September	.42	2.10	.45	1.90
Great Eastern Canal, Nebraska	July-August			.93	1.78
Orr Ditch, Nevada	April-October			.41	7.08
Canal No. 2, Wheatland, Wyo.	June-August	.37	2.53	.24	4.90
Average		.45	4.35	.44	4.15

Eleven stations included in the table furnish results for both 1899 and 1900. The mean duty of water at these 11 stations for 1899 was 4.24 feet in depth. For 1900 it was 4.20 feet. The mean duty of water obtained from the measurement of canals for 1899 is 4.35 feet, and for 1900 4.15 feet. These figures show that the duty based on canal measurements was higher in 1900 than for the preceding season. Attention should be called to the variation in the duty of water under the Upper Canal in Utah in 1899 and 1900. It will be seen by the table that a depth of 6.3 feet was applied in the first season and 3.92 feet in the second season, or a difference of 2.38 feet. This apparent economy was brought about by a scarcity of water during the season of 1900. Conditions were reversed on Canal No. 2, at Wheatland, Wyo. During the season of 1899 the water supply was short. In that year a depth of 2.53 feet was applied to the irrigated land lying under the canal, and during the season of 1900 a depth of 4.90 feet was applied. The excess in depth in 1900 over 1899 is 2.37 feet. This is within one one-hundredth of a foot of the depth saved under the Upper Canal in Utah. The supply to the lands under Canal No. 2 was more than adequate for the needs of the irrigators. It was found impossible to measure the water which ran to waste, and, hence, the discharge records furnished by the water register have been inserted without modification, but they do not give an accurate measure of the water utilized.

Under the Pecos Canal in New Mexico there are great losses from seepage. It was estimated that in 1900 the amount of water that reached the land would have covered the irrigated area to a depth of only 3.01 feet. This is excessive, however, because many farmers under the canal employ wasteful methods of irrigation.

The depth of 2.35 feet given for the Mesa Canal, Arizona, is only for the 6,000 acres on which investigations were made in 1899. The depth of water applied to all lands under this canal in 1900 averaged 2.02 feet. The season of 1900 was very dry, necessitating great economy in the use of water. This scarcity of water was felt, of course, by all the canals in the Salt River Valley, Arizona.

In Utah it would seem that the length of the irrigation season affects but little the volume of water applied to the fields. The eight canals diverting water from Big Cottonwood Creek have an irrigation season of six months, during which time the land irrigated by them was covered to an average depth of 4.33 feet. During an irrigation period of four months the Logan and Richmond Canal and the Logan, Hyde Park and Smithfield Canal delivered enough water to cover the land irrigated by them to a depth of 4.38 feet. The volume supplied by the streams is a much larger factor in the volumes used than the needs of the crops. Big Cottonwood Creek does not furnish enough water to irrigate the land already covered by ditches from it. Farmers have consequently resorted to early irrigation, with the hope that excessive quantities applied in the spring months will tide them over the months of drought, when the discharge of the stream is low.

DUTY OF WATER WHERE MEASUREMENTS WERE MADE ON SMALL CANALS OR LATERALS AND WHERE BUT LITTLE LOSS OCCURRED IN TRANSIT.

The following table gives examples of high duty of water in irrigation observed during 1899 and 1900:

Examples of high duty of water in irrigation.

Location.	Length of irrigation season.	1899.		1900.	
		Rainfall.	Depth of irrigation.	Rainfall.	Depth of irrigation.
		Foot.	*Feet.*	*Foot.*	*Feet.*
J lateral, Wyoming, oats	June-August	0.37	1.55	0.24	1.79
J lateral, Wyoming, corn	do	.37	.70		
Farm, Edgar Wilson, Idaho	May-September	.22	1.48		
Lowest division Gage Canal, California.	Entire year	.47	1.78	.44	1.63
Mean of measurements, Montana Experiment Station.	June-September	.42	1.20	.45	1.45
Farm, I. D. O'Donnell, Montana, alfalfa.				.45	1.30
Middle Creek Ditch, Montana	June-September	.42	2.10	.45	1.90
Western Seed and Irrigation Co., Nebraska.	July-August			.60	1.30
Babcock farm, Nebraska	do			.90	1.97
Experiment farm, Wyoming, oats				.52	1.64
Experiment farm, Wyoming, barley.				.52	1.90
Mean		.38	1.47	.51	1.63

In the case of the lowest division of the Gage Canal, California, the high duty in 1899 was stated to be due to the fact that in that district the citrus fruit trees, which occupy practically all the land served by the Gage Canal, are much younger than those in the other two districts, where the depths supplied were 2.23 and 2.12, respectively, and that none of the trees have reached maturity.

The depth given for the O'Donnell farm, Montana, represents local practice and is not explained.

With reference to the experiments in Nebraska, the irrigation season is quite short and the rainfall comparatively high. The land of the Western Seed and Irrigation Company is a reclaimed swamp, while the Babcock farm is located on a very sandy knoll; hence the difference in the volumes used on the two farms.

In the case of the oats and barley on the Wyoming experiment farm, insufficient water was supplied. It should be added, however, that these crops were grown on newly broken prairie, which needs an exceptionally large volume of water.

In the following table are included examples of low duty of water observed during 1899 and 1900:

Examples of low duty of water in irrigation.

Location.	Length of irrigation season.	1899.		1900.	
		Rainfall.	Depth of irrigation.	Rainfall.	Depth of irrigation.
		Feet.	*Feet.*	*Foot.*	*Feet.*
Hagerman farm, New Mexico	March-October	0.31	15.44	1	14.43
Nevada Experiment Station, wheat	May-August			.15	8.26
Nevada Experiment Station, potatoes.	do			.21	8.16
Sullivan's ranch, Nevada, potatoes.	April-October			.21	7.43
Sullivan's ranch, Nevada, alfalfa	do			.36	6.55
J lateral, Wyoming, potatoes	June-August			.24	3.63
Sigman ranch, Wyoming				.52	3.38
Farm C. G. Goodwin, Idaho	April-August			.26	3.25
Farm A. F. Long, Idaho	April-September	.22	2.40	.27	3.03
Vance farm, Arizona		.39	2.82		
Gage Canal, California	Entire year	.47	2.24	.44	2.23
Farm N. Percell, Idaho	May-August			.26	2.43
Cronquist farm, Utah	June-September	.27	2.60		
Daggett farm, Nebraska	do	1.26	2.47		
Mean		.49	4.66	.36	5.70

The extremely low duty on the Sullivan ranch is in part due to the climate and in part due to the wasteful use of water in Nevada. It is the result of a coarse gravel subsoil, which makes frequent and copious irrigation a necessity.

The low duty on the Sigman ranch, Wyoming, is due to the fact that the soil is very gravelly and sandy.

The figures given for the duty of water on the Percell farm, Idaho, represent an economical use in that State. The use on the Goodwin and Long farms in the same State was generous.

The water applied on the Vance farm in Arizona was probably sufficient in quantity, though more would have been used if it had been available.

The following table summarizes the results for the year 1900. The first column gives the name of the station and the canals located there. All depths given in the table have been reduced to feet. The evaporation records were incomplete, or altogether wanting at a great many of the stations.

Tabular summary of season's measurements of precipitation and duty of water.

Station.	Period during which water was used.	Rainfall.	General duty. Depth of irrigation.	General duty. Depth of irrigation and rainfall.	Location.	Special measurements of duty. Rainfall.	Special measurements of duty. Depth of irrigation.	Depth of irrigation and rainfall.	Remarks.
		Foot.	*Feet.*	*Feet.*		*Foot.*	*Feet.*	*Feet.*	
Carlsbad, N. Mex., Pecos Canal	Mar.-Oct	1	6.99	7.99					Rainfall at Roswell.
	do				Division No. 1	1	4.65	5.65	
	do				Division No. 2	1	3.39	4.39	
	do				Division No. 3	1	2.48	3.48	
	Mar.-Sept				Division No. 4	1	2.27	3.27	
Arizona:									
Tempe Canal	Entire year	.27	2.88	3.15					
Utah Canal	do	.27	2.49	2.76					
Mesa Canal	do	.27	2.02	2.29					
Arizona, Maricopa, and Salt canals.	do	.37	2.45	2.82					
All canals under Salt River	do	.30	2.48	2.78					
Riverside, Cal., Gage Canal	do	.44	2.23	2.67	District No. 1		2.43	2.87	
					District No. 2		2.12	2.56	
					District No. 3		1.63	2.07	
Salt Lake City, Utah:									
Butler Ditch	Apr.-Sept	.49	5.18	5.67					
Brown & Sanford Ditch	do	.49	4.08	4.57					
Upper Canal	do	.49	3.92	4.41					
Farmer Ditch	do	.49	3.62	4.11					
Green Ditch	do	.49	6.14	6.63					
Farr & Harper Ditch	do	.49	5.77	6.26					
Lower Canal	do	.49	3.06	3.55					
Big Ditch	do	.49	2.86	3.35					
Logan, Utah:									
Logan and Richmond Canal	June-Sept	.20	3.81	4.01					
Logan, Hyde Park, and Smithfield Canal.	do	.20	3.07	3.27					
Monroe, Nebr., Great Eastern Canal.	July 1-Aug. 20.	.93	1.86	2.71	Farm Western Seed and Irrigation Company:				Rainfall for July and August. There was very little irrigation outside the limits here placed.
					Squashes	.60	.63	1.23	Rainfall June 1 to Aug. 10.
					Cucumbers	.60	.56	1.16	Do.
					Squashes	.60	.95	1.55	Do.
					Cucumbers	.60	.32	.92	Do.
					Squashes	.60	1.19	1.79	Do.
					Cucumbers	.60	.82	1.42	Do.
					Squashes	.60	1.53	2.13	Do.
					do	.60	1.57	2.17	Do.
					Onions	.60	1.75	2.35	Do.
					Farm H. E. Babcock, Oconee.	.91	1.97	2.88	Rainfall June 1 to Aug. 20, 5 miles from farm.

Wheatland, Wyo., Canal No. 2	June 15–Aug. 31.	.24	4.90	5.14	J lateral:				
					Oats		2.37	2.61	Rainfall June, July, and August. Evaporation, 3.73 feet.
					Potatoes		3.63	3.87	
Laramie, Wyo., Pioneer Canal					Sigman ranch	52	3.38	3.90	Rainfall at Laramie, May–October.
					Webber ranch	52	1.92	2.41	Do.
					Experiment farm:				
					Oats	52	1.64	2.16	Rainfall for growing season. Insufficient water applied.
					Barley	.52	1.90	2.42	Do.
Nampa, Idaho, Boise and Nampa Canal.	Apr.-Sept				Farm A. F. Long	.27	3.03	3.30	
Nampa, Idaho, Payette Valley I. & W. P. Co.	Apr.-Aug				Farm C. G. Goodwin	.26	3.25	3.51	
	May-Aug				Farm N. Percell	.26	2.43	2.69	
Bozeman, Mont., Middle Creek Ditch.	June 4–Sept. 16.	.45	1.90	2.35	Farm J. E. Martin, clover.	.44	1.98	2.42	Rainfall May 1 to Sept. 10.
					Experiment station farm, barley.	.28	1.50	1.78	Rainfall during growth.
					Farm J. L. Patterson, oats.	.39	.84	1.23	Do.
					Experiment station farm:				
					Wheat and clover	.30	.77	1.07	Rainfall May 5 to Aug. 20.
					Oats and peas	.39	.57	.96	Rainfall May 4 to Aug. 25.
					Barley	.28	1.17	1.45	Rainfall May 5 to Aug. 25.
					Oats	.40	1.27	1.67	Rainfall May 2 to Aug. 28.
					Barley	.42	1.96	2.38	Rainfall during growth.
					Clover	.44	2.70	3.14	Rainfall May 1 to Sept. 10.
					Do	.44	1.78	2.22	Do.
Yellowstone County, Mont., Big Ditch.	May 25–Sept. 27.	.45	1.88	2.33	Farm I. D. O'Donnell, alfalfa.	.45	1.30	1.75	Rainfall at Bozeman.
Bitter Root Valley, Montana					Bitter Root stock farm:				
					Orchard	.13	1.48	1.61	Rainfall May 1 to Aug. 14.
					Oats	.13	1.28	1.41	Rainfall Apr. 15 to Aug. 10.
					Do	.13	6.00	6.13	Do.
Reno, Nev.:					Experiment station farm:				
English Ditch	May 16–Aug. 3	.29			Wheat	.15	8.28	8.43	Rainfall May–Aug. Evaporation May 4 to Oct. 24.
	May 17–Aug. 13.	.29			Potatoes	.21	8.16	8.37	Rainfall May–Sept. Evaporation May 4 to Oct. 24.
Orr Ditch	Apr.-Oct	.41	7.08	7.49	Sullivan ranch:				
					Wheat	.30	14.24	14.54	Rainfall Apr.-Aug.
					Potatoes	.21	7.43	7.64	Rainfall May-Sept.
					Alfalfa	.36	6.54	6.90	Rainfall Apr.-Sept.
Prosser, Wash.:									
Prosser Ditch	Apr.-Oct	.26	3.04	3.30					Evaporation May 9–Oct. 29, 2.05 feet.
Sunnyside Canal	do	.28	10.24	10.52					

VALUE OF AN ACRE-FOOT OF WATER.

Where possible the value of the crops grown has been found, and in this way the value of each acre-foot of water applied to the ground has been determined. While this varies for nearly every locality, the figures have considerable value. A number of inquiries have been received as to whether storage reservoirs or irrigation works, whose cost has been determined by careful surveys, would be profitable investments. If the quantity of water to be stored or delivered by the proposed construction is not sufficient to make profitable returns certain, the project is generally abandoned. The following table shows the value of an acre-foot of water, as nearly as can be determined from the measurements made during 1899 and 1900. As will be seen, the figures represent an average of all crops grown, so that they should have general application in the locality where the measurements were carried on.

Value of crops matured for each acre-foot of water used.

	1899.	1900.
Average of six crops in Montana	$18.42	
Average for crops irrigated from—		
Big Cottonwood Creek, Utah	6.34	$6.68
Canal No. 2, Wheatland, Wyo	7.69	3.05
Mesa Canal, Arizona	3.37	
Value of crop from almond orchard under Mesa Canal, Arizona	30.00	
Value for crops irrigated from Gage Canal, California:		
Farm No. 1	207.00	
Farm No. 2	237.00	
Farm No. 3	180.00	
Average for crops irrigated from—		
Orr Ditch, Nevada		2.16
Butler Ditch, Utah		3.95
Brown & Sanford, Utah		3.97
Upper Canal, Utah		6.85
Tanner Ditch, Utah		7.71
Green Ditch, Utah		4.47
Farr & Harper Ditch, Utah		3.00
Lower Canal, Utah		13.67
Big Ditch, Utah		9.84

SILT INVESTIGATION.

The report of irrigation investigations for 1899 gives a brief outline of the work on this subject undertaken by Prof. J. C. Nagle, of the Agricultural and Mechanical College of Texas. For a long time reservoir construction has been checked by the fear of the basins being filled with sediment. The streams of Texas, New Mexico, and Arizona carry large percentages of solid matter in suspension, and as soon as the current is brought to rest in a reservoir this sediment immediately settles to the bottom. Consequently, where irrigation depends on the storage of water the presence of excessive quantities of silt in the water is a serious matter.

The Rio Grande is probably one of the most difficult rivers to deal with in this particular. But few measurements have been made as to

the amount of sediment carried by this stream, but from observation it has been learned that water almost loses its character owing to the amount of silt it contains. At some seasons the discharge comes in waves, so that there may be considerable depth at times and practically a dry channel at others. Many large reservoirs have been projected on this and other streams of the State and Territories mentioned. One large reservoir site on the Wichita River, above Wichita Falls, has been surveyed several times, and estimates have been made for construction, but work has been delayed until the percentage and character of the silt have been determined and some means found to prevent its settlement when the current is brought to rest.

The work of the past two years, under the direction of Professor Nagle, has had this object in view. He has collected samples from the principal streams of Texas and made a study of the reservoir systems of that State and of New Mexico. His progress report can be found on the succeeding pages of this bulletin. That the sediment question is as serious as it was feared can be seen by examining the results he has obtained. Owing to the short time this investigation has been in progress it is difficult to arrive at any valuable conclusion. The facts so far obtained would indicate that there is practically no relation between the percentage of silt contained in the water and the discharge of the stream or the color of the water.

No experiments have as yet been made as to how the silt can best be disposed of. One expedient is to construct a small settling basin in the channel of the stream and convey the water from this to the reservoir site by a canal. As the value of the investigation depends on a more extended study of the various problems met with, a complete report on this subject will not be published until the work has been continued for several seasons.

REPORTS OF SPECIAL AGENTS AND OBSERVERS.

NEW MEXICO.

IRRIGATION ALONG PECOS RIVER AND ITS TRIBUTARIES.

By W. M. Reed. *Special Agent.*

The investigations in New Mexico during the season of 1900 were confined to the districts along the Pecos River and its tributaries. The Pecos River rises in the north central part of New Mexico and flows in a southeasterly direction, passing through what is commonly called the Pecos Valley, in southeastern New Mexico. Entering Texas, it continues in a southeasterly direction and joins the Rio Grande near the eastern extremity of the "Big Bend." There is some irrigation from this stream in Texas—in most instances with indifferent success, although near Barstow, Tex., there is a plant of considerable importance. The knotty problems of irrigation farming are being slowly solved, and undoubtedly in the not distant future this will be one of the most productive sections of Texas. The appropriations of water from the Pecos in Texas have been made from the perennial flow, no storage having been attempted up to the present time. In fact, none has been needed, the perennial flow being equal to all the present demands.

DELAWARE RIVER.

In entering New Mexico from the south along the Pecos, the first tributary met is the Delaware River. This stream rises a little east of south of the Guadalupe Mountains and near the boundary line between Texas and New Mexico. It is an interstate stream. Rising in Texas, it flows nearly east through a portion of both Texas and New Mexico and joins the Pecos on New Mexico soil. However, no interstate problems have arisen, no water having been appropriated from this stream in either the Territory or the State. Some improvements and an appropriation were made in Texas in 1889 by a stockman, but the project was abandoned. The perennial flow is not more than 8 cubic feet per second. The water is "brackish," rising in and flowing through a gypsum country.

BLACK RIVER.

Going north, the next tributary is the Black River. This stream is wholly within New Mexico. It flows from west to east, almost parallel

with the Delaware, and about 20 miles farther north. Its source is in numerous springs. Its perennial flow is about 25 cubic feet per second, and all has been appropriated either by individuals or by the Pecos Irrigation and Improvement Company, the latter's appropriation being 9 cubic feet per second. Some of the appropriations were made twenty years ago, and there are now a number of small, beautiful, and productive farms along this stream. About 400 acres of land is irrigated under the private ditches. The surface soil is rich alluvium, but is nearly all underlaid with gypsum, and where this approaches the surface it causes great loss from ditches and often interferes with successful farming. Fruit and vegetables do exceedingly well in this district. Alfalfa does fairly well, but this crop roots too deep for some of the soil. As the river has much fall, the ditches are usually short and the water is taken directly from the bed of the river, only very low dams being necessary to divert the water into the ditches. The Pecos Irrigation and Improvement Company diverts its portion of the water into its canal and uses it in connection with Pecos River water on the south side of Black River. There has been considerable litigation over water rights on this stream. At present the relations of the owners of rights are amicable, but the lack of method in recording rights in the Territory leaves an opening for much future litigation as soon as old settlers move or die and smart strangers take a hand in irrigation affairs.

PECOS IRRIGATION AND IMPROVEMENT COMPANY.

The next irrigation system met as we go north is that of the Pecos Irrigation and Improvement Company at Carlsbad. This system is described in detail in the report of the investigations made there last year. These investigations have been continued this year in practically the same manner. The results are given in the following pages.

ROCKY ARROYO.

This arroyo begins in the Guadalupe Mountains and runs in an easterly direction, joining the Pecos about 10 miles north of Carlsbad. It has a surface flow near its head of 10 cubic feet per second, but alternately sinks in the gravel bed and rises as it flows toward the Pecos. There is very little land along this stream susceptible of irrigation—not more than 100 acres. The gravel substrata prevents oversaturation and gardening is carried on successfully. There is a reservoir site on this stream, the waters from which could be used on the Carlsbad system.

SEVEN RIVERS.

This stream joins the Pecos from the west 17 miles above Carlsbad. It is formed by several small springs and has a flow of 20 cubic feet per second. The soil is fertile in this district and the water easily

applied to the land. The water is often taken directly from the spring and carried to the land by a short ditch with practically no more expense than the cost of ditch construction. About 700 acres are in cultivation with this water, and the fact that in most instances the appropriation is for all the water in the particular spring from which it is taken has reduced the litigation in this district to a minimum. A small quantity of water reaches the Pecos from this stream. The bed of the stream is filled with gravel and the water alternately rises and sinks during its flow. The duty of water on this stream is only about 35 acres per cubic foot per second. Under more scientific methods this duty can be increased.

PEÑASCO RIVER.

This stream rises in the western part of Eddy County and flows in an easterly direction, joining the Pecos 10 miles north of McMillan. It ranges in flow from 10 cubic feet per second at low water to 12,000 cubic feet per second during extreme flood time. The water of this stream has all been appropriated for many years. Much litigation has taken place; court decisions have been rendered and then other suits have been brought to determine the meaning of the first decisions. The latest decision of the court has been practically nullified by the elements. The court made an award of water reaching a certain point. During the past season the floods destroyed the dam and tore up the bed of the river, exposing gravel for some distance, and no water now reaches this point, sinking above and not rising until some distance below. Adjustment must again be undertaken and probably the court will again be called upon. The area irrigated is not over 700 acres and a portion of this receives water during flood time only. The irrigated area on this stream can be extended only by building reservoirs near its head or by putting submerged dams along its course for the purpose of raising to the surface the water that now flows through the gravel.

CHAVES COUNTY.

The Pecos River furnishes very little water for irrigation in Chaves County, the supply in this county coming from the North and South Spring rivers, the North, Middle, and South Berrendos, the Rio Hondo, and artesian wells. Except the canal of the Felix Irrigation Company (formerly Northern Canal Pecos Irrigation and Improvement Company), the ditches are owned by individuals or community organizations, and are governed by rules laid down by the owners at annual meetings. The Felix Irrigation Company's canal was constructed in 1889 and 1890, and is taken from the Rio Hondo below where this river is joined by North Spring River and the Berrendos. The canal crosses South Spring River, and appropriates all the surplus water of that stream at the point of crossing. (See fig. 11.) This canal is 30 feet wide on the bottom, with side slopes one and one-half horizontal

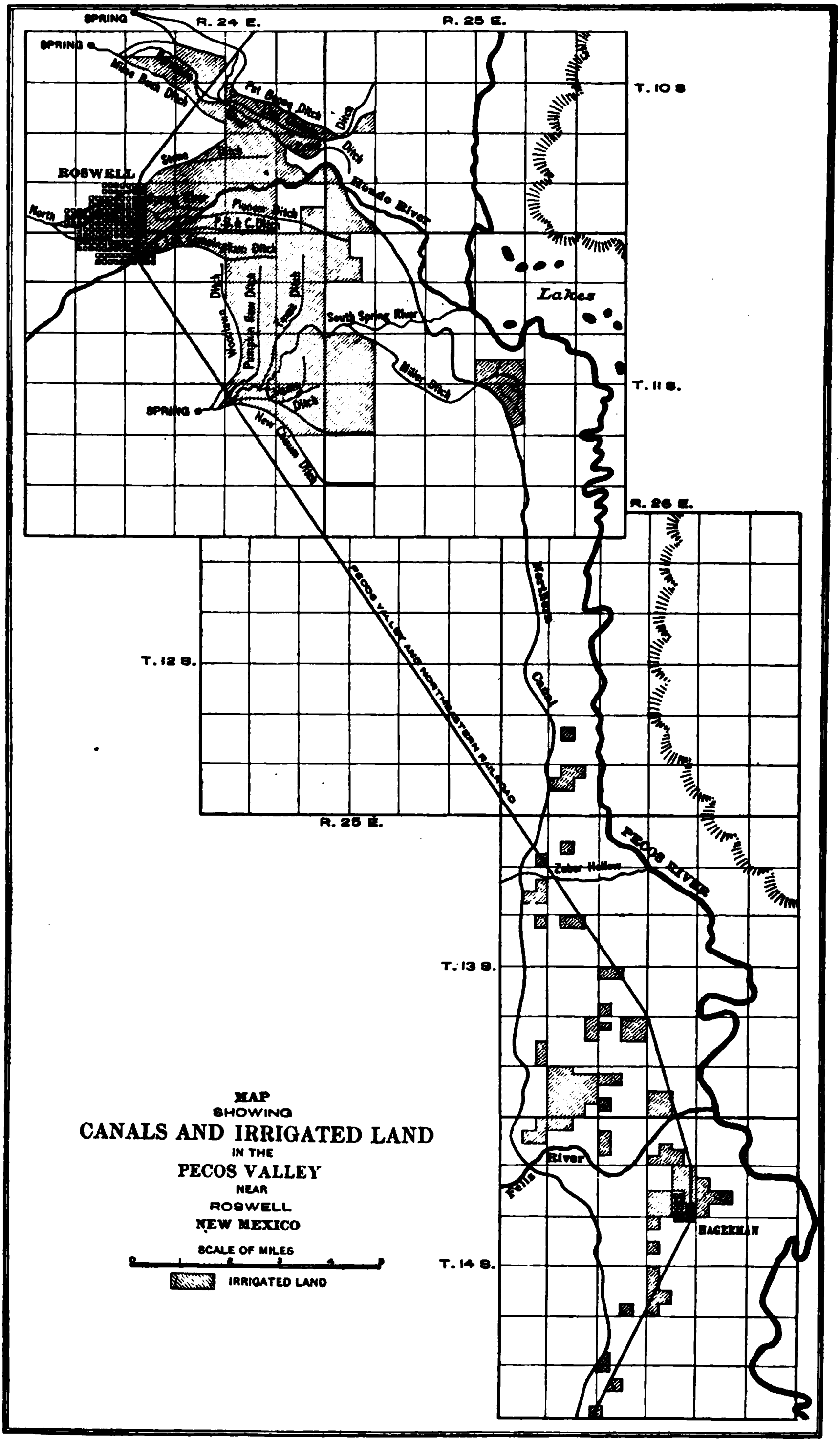


Fig. 11.—Map showing canals and irrigated land in the Pecos Valley, New Mexico.

VIEW ON BERRENDO RIVER.

to one vertical, constructed to carry water 6 feet in depth, and has a fall of 1 foot in 5,000. The canal has banks on both sides nearly all its length. There is very little gravel or conglomerate along its line, but considerable gypsum is encountered. This has caused a great loss of water. During the first year after its construction the loss in the first 25 miles was about 80 per cent. Frequently breaks in the gypsum would divert the entire flow. These places were relined with better material, and now after ten years of operation the loss has been reduced to 25 per cent. The efforts of the owners to increase the efficiency of this canal were greatly aided by the Hondo during flood time. The Hondo at such times carries from 5 to 8 per cent of silt, and as much of this water as possible was allowed to flow through the canal. The decreased grade made the current slower, and much of this silt was deposited, making an almost impervious lining. The silt has another beneficial effect. In this climate in clear water there is always a heavy aquatic growth, obstructing the canal almost entirely, if not removed. The silt in the water forces this growth to the bottom and opens the channel. Of course this necessitates the cleaning of the canal, but this can be done at a time when there is no demand for water. In years when the floods come late in the season the aquatic growth must be removed by mechanical methods. The system of distributing the water under this canal is practically the same as the one used by the Pecos Irrigation and Improvement Company in Eddy County, described last year. The average flow at the intake of the canal is 80 cubic feet per second; the acreage under cultivation this year 3,700 acres; the available water at point of delivery 60 cubic feet per second, and a duty of water this season of 61.6 acres per cubic foot per second of flow. In instances under this system where water was sold by the acre-foot, fair crops have been produced by the use of 1½ acre-feet per acre. Add to this the rainfall of 12 inches (estimated by comparison with gage at Roswell), and it is found that 30 inches of water over the fields has produced good average crops in this district. The fact that under this system the amount of water is limited and the amount of good tillable land is unlimited has caused a high duty of water, and partially demonstrates what can be accomplished in other similar districts when better and more economical methods of handling the water are used.

THE ROSWELL DISTRICT.

The land of this district is watered by North and South Spring rivers; North, Middle, and South Berrendos; Rio Hondo, and artesian wells. This district is the most advanced of any of the Pecos system from a standpoint of successful irrigation. It was settled and irrigation begun twenty-five years ago. The farms are productive and most of the farmers are successful. The water supply is constant, the

springs in this district having no perceptible variation either in summer or winter, in wet or dry seasons. The farmer knows just how much water he has, can irrigate just when he pleases, and the point that he must thoroughly study and determine is when to irrigate and just how much water to use. The irrigated district is being extended a little each year and in time the limit of duty of water will be reached. There has been very little friction among the water users in this district in the past, yet it is impossible from present data to know the exact relation between the water rights of the various ditches. Some of the ditches are not of official record; others have filed their claims, but in such a way that they would be of little help in a court. The filings are made in the office of the probate clerk of the county. The forms vary in each individual case. They are scattered through the other records of the office, and it is considerable of a task to search out the water records of the county.

A system of time rotation is adopted in the distribution of water from the various community ditches. The period of rotation is decided upon at the annual meeting of the owners. This is usually from eight to twelve days. During this period each owner has full control of the ditch for a time that is in the same proportion to the whole period as his interest is to the whole interest. This system, when first adopted by the Woodlawn Canal, was opposed by some owners, but has worked so satisfactorily that it is now in almost universal use in this district. It has a tendency to increase the duty of water. The owners, knowing just when and how much water they have, can, by scientific handling, increase their irrigated area until the limit is reached. Below is given the time schedule of one of the ditches in this district:

Stone Ditch schedule, 1900.

Name.	Acres.	Hours.	Begins—	July.	August.	September.	October.
				Days.	*Days.*	*Days.*	*Days.*
Boon	50	60	6 p. m.	15,26	6,17,28	8,19,30	11,22
Crosson	10	12	6 a. m.	18,29	9,20,31	11,22	3,14,25
Kingston	30	36	6 p. m.	18,29	9,20,31	11,22	3,14,25
Fuqua	10	12	6 a. m.	20,31	11,22	2,13,24	5,16,27
Pickering	10	12	6 p. m.	20,31	11,22	2,13,24	5,16,27
Crawford	20	24	6 a. m.	21	1,12,23	3,14,25	6,17,28
Hastings	10	12	6 a. m.	22	2,13,24	4,15,26	7,18,29
Whiteman	10	12	6 p. m.	22	2,13,24	4,15,26	7,18,29
Snyder	10	12	6 a. m.	23	3,14,25	5,16,27	8,19,30
Reed	20	24	6 p. m.	23	3,14,25	5,16,27	8,19,30
King	40	48	6 p. m.	13,24	4,15,26	6,17,28	9,20,31

The abundance of water in this district has led to the error so common in irrigated districts. The application of large quantities of water to the land without proper attention to drainage has caused overwetting in some localities, and now a careful system of drainage is necessary to reclaim the land. Experiments in drainage have been undertaken by Professor Tinsley of the New Mexico Agricultural Experiment Station, of which mention will be made later.

The following table gives interesting data regarding the ditches of the Roswell district:

Data regarding ditches of the Roswell district.

Name of ditch.	Source.	Ownership.	Water carried.	Area cultivated.	Duty per cubic foot per second.	Record.
			Cub. feet per sec.	*Acres.*	*Acres.*	
Woodlawn	South Spring River.	Community	12	600	50	Recorded; incorporated.
Chisum	do	J. J. Hagerman	14.22	1,200	84.39	Nothing of record.
Pumpkinrow	do	Community	23.13	1,200	51.44	Recorded; affidavit.
Texas	do	do	10.03	500	49.85	Nothing of record.
J. M. Miller	do	do	11.27	250	22.18	Do.
Stone	North Spring River.	do	25	900	36	Recorded; incorporated.
Lea Cunningham.	do	do	13.20	700	52.95	Do.
Town [1]	do	do		450	26.31	Nothing of record.
Pierce, Cunningham & Ballard.	do	do	17.10			Recorded; incorporated.
Blasheck	do	G. F. Blasheck	22.15	8		Recorded; private ditch, principally milling.
Pioneer	do	Community	12.17	480	39.43	Recorded; 2 sets of papers.
Milne-Bush Co. No. 1.	South Berrendo.	Milne-Bush Cattle Co.	6.91	525	47.90	Nothing of record.
Last Chance	do	Hurd & Clements.	5	200	40	Recorded; affidavit of appropriation.
Thompson	do	A. M. Thompson	3.45	80	25.53	Do.
Milne-Bush Co. No. 2.	Middle Berrendo.	Milne-Bush Cattle Co.	4.05	([2])		Do.
Cosmo Sedilo	do	Cosmo Sedilo	1.90	30	15.79	Nothing of record.
Last Chance Feeder. [3]	do	Hurd & Clements.	3.11			Recorded; affidavit of appropriation.
Pat Boone	North Berrendo.	W. G. Urton	6.84	200	29.24	Nothing of record.
Hondo Falls	Hondo	Community	0	0		Recorded; incorporated.
Sol Jacobs	do	Chas. Bremond	10.01	180	17.98	Nothing of record.
Perry Fountain	do	Community	0 to 30	250		Recorded; incorporated.
Lea Cockrell	do	do		80		
Lincoln County	do	do	0 to 40	0		Do.
Long Truxton	do	do	0 to 100	110		Do.
Cockrell	do	do		60		Do.
Rock Corrall	do	do	0 to 27			
Northern Canal	do	do	60	3,700	61.66	Do.

[1] Water carried in the Pierce, Cunningham & Ballard.
[2] See Milne-Bush Co. No. 1.
[3] Used with Last Chance.

THE HONDO.

For the past thirty years the Hondo for a distance of 25 miles above its junction with North Spring River has not been a perennial stream. It is reported that previous to that time there was a constant flow. An old irrigation system, known as the Missouri Plaza, and situated 15 miles west of Roswell, was abandoned in 1869, and its existence goes to show that previous to that time there was more water in the Hondo. Water does not now reach beyond the narrow valleys except in flood time.

The Hondo is formed by the junction of the Rio Benito and Rio Ruidoso, in Lincoln County. Both of these streams rise in the White

Mountains, about 20 miles apart, and flow down through narrow and deep but fertile valleys. Their flow is not more than 15 cubic feet per second each, and the farming is done right along their banks. The return waters make the stream appear to have a greater flow. The total area in cultivation is about 2,000 acres, and from best data obtainable has not been increased any during the last twenty years. In most instances the farming methods are crude. Water is used lavishly and cultivation sparingly. The majority of the inhabitants are Spanish speaking, and their methods are those of a past generation. Crops are still gathered with the old-fashioned sickle, carried on the backs of "burros," and thrashed by the tramping of half-wild bronchos or herds of goats. Yet so fertile is the valley and so perfect the climate that fruit and vegetables raised here are superior to those of almost any other section of the United States. Below the junction of these streams, on the Hondo proper, for a distance of 15 miles, the same conditions prevail, except that the water supply is less and the crop not always so sure. For 10 miles along the course of the Hondo, west from Roswell, are numerous ditches. They receive water only during flood time, yet this is sufficient to produce at least two crops of alfalfa, and frequently three, in a season, and never fails to mature sorghum and the head corns. There is at least 500 acres of these crops farmed in this way. Success under these conditions indicates that in most other districts in this valley more water than is necessary has been used. As there is only an intermittent flow along this portion of the stream, it is difficult to adjust the water during the periodical rises, and much friction and some litigation have resulted. It was in this district that the case of Millheiser et al. *v.* Long et al. was instituted. This was a case in which the meaning of "appropriation" was to be decided, the complainants taking the position that the filing of a claim to a certain quantity of water and the building of a ditch of sufficient size to carry it did not constitute an appropriation unless followed by a beneficial use of the water. The district court decided in favor of the defendants. The Territorial supreme court reversed this decision. Following is the syllabus by the court. (Pacific Reporter, vol. 61, p. 111.)

MILLHEISER ET AL. *v.* LONG ET AL.

(Supreme Court of New Mexico, May 3, 1900.)

Waters—Appropriation—Extent—Priority—Appeal—Findings—Review.

(1) Capacity of ditch alone does not constitute a valid appropriation of water unaccompanied by application of water to some beneficial use.

(2) Where two ditches are receiving water from the same stream—one constructed in 1885 and the second in 1888—the owners of water rights in the first at the time the second is constructed have a prior appropriation of so much water as has been actually applied by them to some beneficial purpose, but sales of water rights by them, for the use of water to be conducted through the first ditch in excess of valid appropriation by owner of water rights in the first ditch, after

ARTESIAN WELL, L. F. D. FARM, ROSWELL, N. MEX.

water has been diverted and beneficially applied through the second ditch, is void as to such excess, as against the rights of valid appropriators through the second ditch.

(3) Where the controversy involves the prior appropriation of water between those claiming water rights in two ditches constructed at different times, proof which fails to show what tract or tracts of land water was conducted upon, how much of the land, for what years, and what portion each year is not sufficiently specific to base a decree upon as to the prior appropriation of the water, where numerous tracts of land and ten years' time are involved.

(4) Where, in a cause tried by a court without a jury, the court fails to find material facts, which, being considered, demonstrate that the decree rendered in the court below was manifestly wrong, this court will consider such facts to enable the court to arrive at a just conclusion.

(5) The doctrine of prior appropriation governs the distribution of water in this case.

The effects of this decision will undoubtedly be to destroy any attempts at monopoly of water and increase its actual, beneficial use.

ARTESIAN WELLS.

There are now about 200 artesian wells (Pl. V) in Roswell and vicinity, varying in depth from 180 to 700 feet and in flow from 2 gallons per minute to 1,800 gallons per minute. A large percentage of the wells are used only for domestic and stock purposes. In a few instances they are used for irrigation upon farms. One having a flow of 600 gallons (1⅓ cubic feet per second) furnishes sufficient water for a 40-acre apple orchard 6 years old, and besides supplies water for a very complete system for domestic use. Another well of about the same capacity is supplying a 20-acre orchard and 40 acres in other crops. Several wells have been bored this year solely for irrigation purposes, and it is possible that this supply will develop the highest water duty in this section. The fact that the water supply is limited and the area of land on which it can be used is unlimited will cause care to be exercised in the use of water and the best results obtained.

DRY FARMING.

While irrigating water has been considered absolutely necessary in order to raise crops at all in this district, a very interesting experiment in dry farming has been in progress for the last three years. This has been conducted about 5 miles northwest from Roswell by Mr. G. S. Nutter, formerly a farmer in Illinois. This has not been an experiment purely for scientific knowledge, but Mr. Nutter has depended entirely upon his success at this kind of farming for his living. His land is a sandy loam underlaid with gravel, in some instances loose, in others a conglomerate. At present there is no means of supplying water for irrigation, and the rainfall is the only moisture this land has ever had. This year the rains until September were very light, and while no actual measurements were made there was not sufficient rainfall at any one time until September 3 to

wet this cultivated land to a depth of more than 6 inches below the surface. Since September 3 there have been frequent showers. Mr. Nutter has in cultivation 40 acres in Kafir corn, 5 acres in Indian corn, and about 1 acre in garden, planted to beans, tomatoes, and potatoes. Everything except Indian corn compares favorably with the same kind of crops in the irrigated district. Success lies in the intense cultivation. A dust blanket is maintained over the entire surface and a minimum amount of moisture is lost by evaporation. None of the rainfall is allowed to escape at any time during the year. An inch of water in the winter is turned under and as carefully stored as if it came in the growing season, and to this practice Mr. Nutter attributes his success. The success of this experiment perhaps points to a way of making safer the stock business on the Great Plains by raising forage to supplement natural grasses when storms or drought threaten great loss.

DRAINAGE.

At the same time that Mr. Nutter was husbanding every drop of water possible, 6 miles to the southeast another experiment looking for different results was being undertaken. Prof. J. D. Tinsley, of the New Mexico Agricultural Experiment Station, put in a drainage system on a water-logged tract of land 4 acres in extent 1 mile east of Roswell. Considerable land in the immediate vicinity has become swampy, and this tract, a portion of which was actually submerged, was selected for the experiment. Professor Tinsley will issue a bulletin upon this experiment, and nothing will be said here more than to note its apparent effect and to demonstrate the loss of water by seepage from ditches. The land is now dry on the surface and apparently in condition to produce good crops. This particular piece of land was not ruined by overirrigation, but by seepage. The Pierce, Cunningham and Ballard Ditch runs just above this piece of land and directly opposite to it, and passes, for about 50 feet, over a soil largely composed of gypsum, and during the season when no water was being applied to the land the drainage pipe was discharging about one-fourth cubic foot per second. As the ditch here was carrying only about 6 cubic feet per second, it is easily seen that a large percentage was lost in this one encounter with gypsum. There is a good deal of land in this vicinity that must be drained in order to make it of any value, and the experiment of Professor Tinsley will be watched with much interest by owners of water-logged land.

HAYNES DITCH.

There is but one irrigation ditch in Chaves County direct from the Pecos River. This is taken from the river 40 miles above Roswell, and is known as the Haynes Ditch. It was first taken out in 1893, and in 1895 was temporarily abandoned owing to the destruction of

the dam. A new dam of brush and rock was constructed in the winter of 1899 and 1900, but suffered the fate of the first one during the summer of 1900. This ditch is taken out of the river at the head of what Mr. P. E. Harroun, C. E., in his report to the New Mexico Irrigation Commission in 1898 termed the Lower Pecos. Above this point for a distance of 50 miles the Pecos is frequently dry, but there is evidently an underflow, for a limestone formation just above the Haynes Dam forces the water to the surface, and during the drier times the river furnishes a supply of not less than 30 cubic feet per second. The water will have to be raised but 2 feet above low water in order to supply the Haynes Ditch, and during the coming winter a cable wire dam, detachable at one end, will be constructed. The construction will allow the dam to be carried to one side of the river during high water and easily replaced when the water recedes. There is now about 200 acres in alfalfa under this ditch, and it is planned to put in 2,000 acres. Both the soil and the water seem well adapted to the production of alfalfa, and as the intention is to make this a great stock enterprise, it seems as though success would follow. The open range is very large and capable of pasturing immense herds most of the time, but occasionally years will come when great loss will take place if there is no way of getting additional feed. This irrigation system ought to supply this want.

UPPER PECOS.

According to Mr. Harroun's report the Upper Pecos has about 11,500 acres under cultivation, and has reached its limit unless storage reservoirs are provided. The irrigated lands are to be found at the most available points, from its head down as far as Puerto de Luna. The ditches are mostly community concerns, and while the methods used are not modern, they seem to suit the people using them, and until the tide of progress reaches this section and the progressive, profit-seeking American appears, no advancement will take place and the happy methods of a past generation will continue.

MEASUREMENTS OF DUTY OF WATER, 1900.

The measurement of the water used under the canals of the Pecos Irrigation and Improvement Company, which was begun in 1899, was continued during the season of 1900. There has been much greater humidity during this season, consequently much less evaporation. Crops generally have been better. Some crops that did not prove a success in former years were not planted this year, and others better adapted to the soil and climate were substituted, with much better success to the farmers. The following tables, made up from the records of the company, give the data relating to the use of water during the season of 1900:

Acreage of crops and water delivered for the season of 1900, division No. 1, Pecos Irrigation and Improvement Company.

Name.	Soil.	Acreage of crops.										Water delivered, acre-feet.									Depth of water.	Yield per acre.		
		Alfalfa.	Corn.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Grass.	Total.	March.	April.	May.	June.	July.	August.	September.	October.	Total.		Alfalfa.	Corn.	Cane.
																					Feet.	*Tons.*	*Bush.*	*Tons.*
Bush, William	Sandy	4	14	5						1	24	8.28	35.04	12.43	22.61	25.72	8.11	0.69	8.03	120.91	5.04	(1)	20	2.5
Cameron, J. O.[2]	do	4			1						5	1.01	1.72	1.90	3.29					7.92	1.58	3		
Carlsbad (town)	Varied				5		5		100	5	115	61.63	51.32	49.59	77.96	28.55	87.99	32.44	32.90	422.38	3.67			
Chambers	Sandy	1	1		1					2	5	5.36	8.17	2.88	3.69		4.81			24.91	4.98	(1)		
Crawford, A. J	Adobe	12	10	14							36	9.88	16.14	20	21.95		28.74			96.71	2.69	3	35	5
Cornet, J. H	Sandy		3		2						5		7.85	7.69	6.34	7.56	5.03			34.47	6.89		30	
Freeman, A. A.[3]	do	3			5	0.5	1			.5	10	18.43	11.40		18.26	8.46	38.43			94.98	9.50	3		
George, Edgar	Adobe		4								4				17.94					17.94	4.48		30	
Herd & White[4]	do	25			5						30		50.04	9.47	21.91		6.11			87.53	2.92	(1)		
Holt[5]	Sandy	40	15	5	5						65	85.23	82.22	27.62	99.24	32.13	125.44	20.35	22.44	494.67	7.61	3.5	35	4
Holloway[6]	Adobe		10		11						21		6.35	2.69	12.80	3.20	1.53			26.57	1.27		30	
Hagerman, J. J.[7]	Gravel	40			30				20		90	161.73	197.44	115.53	70.84	122.66	153.57	98.72	89.73	1,010.22	14.43	(1)		
Illingworth	Sandy	5								1	6	14.78	5.52		7.04	7.42	10.86			45.62	7.60	(1)		
James, H. J	do	2			1					1	4	3.76	3.55	5.66	8.07		3.63			24.67	5.48	(1)		
James, J. H.[8]	do	4			1						5	.66	.87	1.55	3.78		3.70	2.59	2.31	15.46	3.09	New.		
Love, R. P.[5]	do	1			4						5	4.84		4.27	3.79	8.42	9.59	4.49		35.40	7.08	(1)		
Do	Gravelly	11		3		1					15		9.43	16.73	16.32		20.65			63.13	4.21	3		3.5
La Huerta	Varied								30		30	58.44				36.25	36.68	110.45	54.83	296.65				
McLenathen, by Harbert.	Adobe	10	30	5			1				46		27.61	13.91	75.79		48.99			166.30	3.62	2	40	3.5
Miller, M. D.[9]	Sandy		7		1	1					9		12.22	5.35	8.81	8.29	7.26			41.93	4.66		40	
Merrifield, C. O	Adobe	53	12	23	2	1	1	2			94	170.29	224.21	105.62	193.59	157.16	193.09	74.14		1,118.10	11.89	(1)	30	3
McAuslin	Sandy		7	5			1				13		2.25	32.48	20.89	9.88	16.22			81.72	6.29		15	2
McKeen, J. O	Adobe	4	22	10							36		13.62	19.37	46.61	5.21	31.46			116.27	3.23	New.	25	4
Osborn, I. S.[10]	do	60									60	37.33	25.44	15.44	49.16	8.19	34.01			169.57	2.82	2		
Quinones			1				1				2						4.10			4.10	2.05			
Rio Vista	Varied	8			3						11	13.87	20.47	7.75	6.04	5.75	14.68	10.85	8.46	87.87	7.99	(1)		
Rayroux	Sandy	17	5		1		1				24	13.31	39.51		52.43	17.40	31.42	2.62		156.69	6.53	3	10	
San Jose	Adobe		20				10				30		25.68	6.66	21.46	27.79	29.52	13.27	2.95	127.33	4.24		20	
Sharp, M.[5]	Sandy		4		22						26	42.05	86.13		22.44	8.46	19.34	12.61		191.03	7.35		30	
Sholtz	Adobe		10	5							15	7.42	8.88	2	13.32	11.78	14.88	6.44		64.72	4.31		25	3
Tansil, R. W.[5]	Sandy	18			2						20	14.01	15.45	12.77	12.77	4.32	16.54	5.50	16.35	97.71	4.89	2		
Tallant	do	20	6	30	2		1				59	36.27	58.12	34.68	53.06	15.61	27.82	2.23		227.79	3.86	1.5	10	1.5
Tucker[11]	Gravelly			2	1		1				4													3
Tracy, F. G	do	3								1	4		4.83	5.87	6.69		8.91	1.90		28.20	7.05	(1)		
Do.[5]	Sandy	13			22						35		24.95	63.88	36.32	37.14	16.45	10.23		188.97	5.40	3		
Wardman, Geo	do	12			1	1				3	17	9.66	14.86	15.82	13.82	13.84	6.43	8.11	12.81	95.35	5.59	3		
Watkins (now Finley).	Adobe	20									20		43.12	20.30	30.90			8.47		102.79	5.14	2.5		

Webster, G. H	do		73								73		27.16	70.61		16.83	38.33		6.57	159.50	2.18		35	
Do	do	300	127	30		20					477	128.80	196.08	93.55	146.97	107.52	297.07	101.52	(12)	1,071.51	2.25	2.5	30	
Wersell (Eddy land).	Sandy	22	5	3	8						38	47.02	23.59	9.68	29.96	31.63	24.78			166.66	4.39	2.5	30	3
Wilson	do	2			2		1				5	4.91	3.96	1.89	2.77	8.76	2.49			24.78	4.96	(1)		
Total		714	386	140	138	24.5	24	2	150	14.5	1,593	958.97	1,385.20	815.64	1,259.63	775.93	1,428.66	527.62	257.38	7,409.03	4.65			

[1] Pastured.
[2] Big fruit yield.
[3] Big crop fruit.
[4] Orchard young; some fruit.
[5] Large fruit yield.
[6] Hail destroyed fruit.
[7] In June bad moss in canal.
[8] Orchard planted this season.
[9] Fruit, grapes, etc.
[10] Rains overflowed land.
[11] No record of water.
[12] No record.

Acreage of crops and water delivered for the season of 1900, division No. 1, Pecos Irrigation and Improvement Company.

Name.	Soil.	Acreage of crops.										Water delivered, acre-feet.									Depth of water.	Yield per acre.		
		Alfalfa.	Corn.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Grass.	Total.	March.	April.	May.	June.	July.	August.	September.	October.	Total.		Alfalfa.	Corn.	Cane.
																					Feet.	*Tons.*	*Bush.*	*Tons.*
Bush, William	Sandy	4	14	5						1	24	8.28	35.04	12.43	22.61	25.72	8.11	0.69	8.03	120.91	5.04	(1)	20	2.5
Cameron, J. O.[2]	do	4			1						5	1.01	1.72	1.90	3.29					7.92	1.58	3		
Carlsbad (town)	Varied				5		5		100	5	115	61.63	51.32	49.59	77.96	28.55	87.99	32.44	32.90	422.38	3.67			
Chambers	Sandy	1	1		1					2	5	5.36	8.17	2.88	3.69		4.81			24.91	4.98	(1)		
Crawford, A. J	Adobe	12	10	14							36	9.88	16.14	20	21.95		28.74			96.71	2.69	3	35	5
Cornet, J. H	Sandy		3		2						5		7.85	7.69	6.34	7.56	5.03			34.47	6.89		30	
Freeman, A. A.[3]	do	3			5	0.5	1			.5	10	18.43	11.40		18.26	8.46	38.43			94.98	9.50	3		
George, Edgar	Adobe		4								4				17.94					17.94	4.48		30	
Herd & White[4]	do	25			5						30		50.04	9.47	21.91		6.11			87.53	2.92	(1)		
Holt[5]	Sandy	40	15	5	5						65	85.23	82.22	27.62	99.24	32.13	125.44	20.35	22.44	494.67	7.61	3.5	35	4
Holloway[6]	Adobe		10		11						21		6.35	2.69	12.80	3.20	1.53			26.57	1.27		30	
Hagerman, J. J.[7]	Gravel	40			30				20		90	161.73	197.44	115.53	70.84	122.66	153.57	98.72	89.73	1,010.22	14.43	(1)		
Illingworth	Sandy	5								1	6	14.78	5.52		7.04	7.42	10.86			45.62	7.60	(1)		
James, H. J	do	2			1					1	4	3.76	3.55	5.66	8.07		3.63			24.67	5.48	(1)		
James, J. H.[8]	do	4			1						5	.66	.87	1.55	3.78		3.70	2.59	2.31	15.46	3.09	New.		
Love, R. P.[5]	do	1			4						5	4.84		4.27	3.79	8.42	9.59	4.49		35.40	7.08	(1)		
Do	Gravelly	11		3		1					15		9.43	16.73	16.32		20.65			63.13	4.21	3		3.5
La Huerta	Varied								30		30	58.44				36.25	36.68	110.45	54.83	296.65				
McLenathen, by Harbert.	Adobe	10	30	5			1				46		27.61	13.91	75.79		48.99			166.30	3.62	2	40	3.5
Miller, M. D.[9]	Sandy		7		1	1					9		12.22	5.35	8.81	8.29	7.26			41.93	4.66		40	
Merrifield, C. O	Adobe	53	12	23	2	1	1	2			94	170.29	224.21	105.62	193.59	157.16	193.09	74.14		1,118.10	11.89	(1)	30	3
McAuslin	Sandy		7	5			1				13		2.25	32.48	20.89	9.88	16.22			81.72	6.29		15	2
McKeen, J. O	Adobe	4	22	10							36		13.62	19.37	46.61	5.21	31.46			116.27	3.23	New.	25	4
Osborn, I. S.[10]	do	60									60	37.33	25.44	15.44	49.16	8.19	34.01			169.57	2.82	2		
Quinones			1				1				2						4.10			4.10	2.05			
Rio Vista	Varied	8			3						11	13.87	20.47	7.75	6.04	5.75	14.68	10.85	8.46	87.87	7.99	(1)		
Rayroux	Sandy	17	5		1		1				24	13.31	39.51		52.43	17.40	31.42	2.62		156.69	6.53	3	10	
San Jose	Adobe		20				10				30		25.68	6.66	21.46	27.79	29.52	13.27	2.95	127.33	4.24		20	
Sharp, M.[5]	Sandy		4		22						26	42.05	86.13		22.44	8.46	19.34	12.61		191.03	7.35		30	
Sholtz	Adobe		10	5							15	7.42	8.88	2	13.32	11.78	14.88	6.44		64.72	4.31		25	3
Tansil, R. W.[5]	Sandy	18			2						20	14.01	15.45	12.77	12.77	4.32	16.54	5.50	16.35	97.71	4.89	2		
Tallant	do	20	6	30	2		1				59	36.27	58.12	34.68	53.06	15.61	27.82	2.23		227.79	3.86	1.5	10	1.5
Tucker[11]	Gravelly			2	1		1				4													3
Tracy, F. G	do	3								1	4		4.83	5.87	6.69		8.91	1.90		28.20	7.05	(1)		
Do.[5]	Sandy	13			22						35		24.95	63.88	36.32	37.14	16.45	10.23		188.97	5.40	3		
Wardman, Geo	do	12			1	1				3	17	9.66	14.86	15.82	13.82	13.84	6.43	8.11	12.81	95.35	5.59	3		
Watkins (now Finley).	Adobe	20									20		43.12	20.30	30.90			8.47		102.79	5.14	2.5		

Webster, G. H	do	....	73	....	....	....	....	....	....	....	73	......	27.16	70.61	......	16.83	38.33	......	6.57	159.50	2.18	......	35	......
Do	do	300	127	30	....	20	....	....	....	....	477	128.80	196.08	93.55	146.97	107.52	297.07	101.52	([12])	1,071.51	2.25	2.5	30	......
Wersell (Eddy land).	Sandy	22	5	3	8	....	....	....	....	....	38	47.02	23.59	9.68	29.96	31.63	24.78	......	......	166.66	4.39	2.5	30	3
Wilson	do	2	....	....	2	....	1	....	....	....	5	4.91	3.96	1.89	2.77	8.76	2.49	......	......	24.78	4.96	([1])	......	......
Total	......	714	386	140	138	24.5	24	2	150	14.5	1,593	958.97	1,385.20	815.64	1,259.63	775.93	1,428.66	527.62	257.38	7,409.03	4.65	......	......	......

[1] Pastured.
[2] Big fruit yield.
[3] Big crop fruit.
[4] Orchard young; some fruit.
[5] Large fruit yield.
[6] Hail destroyed fruit.
[7] In June bad moss in canal.
[8] Orchard planted this season.
[9] Fruit, grapes, etc.
[10] Rains overflowed land.
[11] No record of water.
[12] No record.

Acreage of crops and water delivered for the season of 1900, division No. 2, Pecos Irrigation and Improvement Company.

Name.	Soil.	Acreage of crops.									Water delivered, acre-feet.									Depth of water.	Yield per acre.		
		Alfalfa.	Corn.	Cane.	Beets.	Orchard.	Beans.	Trees.	Grass.	Total.	March.	April.	May.	June.	July.	August.	September.	October.	Total.		Alfalfa.	Corn.	Cane.
																				Feet.	Tons.	Bu.	Tons
Benson, R. S.[1]	Adobe	580	175	115		20				890	44.40	576.48	322.29	310.94	295.31	440.73	369.67		2,359.82	2.65	3.5	82	3
Bolles, R. J.[1]	do	400	140	15		30	20			605	50.50	536.13	565.06	420.46	238.02	595.53	377.08	156.52	2,939.30	4.86	3	30	3
Breneis, Killian	do	7	31	1						39		43.53	1.66	33.31	11.51	12.96			102.97	2.64	2.5	28	3
Bryant, F. E	do	60	80							140		30.01	84.67	76.24	55.62	63.36	60.10	21.34	391.34	2.80	1.5	20	
Beet Sugar Co	do	160								160		163.91	36.34	49.08			101.07	72.55	422.95	2.64	New.		
Cowden & Keyser[2]	do	136	110	15			1			262	155.24	154.45	161.35	220.10	102.16	189.86	70.63		1,053.79	4.02	2	37	3
Demorest, C. J.[3]	do		24							24			50.10	24.36	2.58	6.94			83.98	3.50		38	
Do.[4]	do	30				12	1			43	109.66	69.74	84.39	132.28	115.10	24.22	20.49		555.88	12.93	1.5		
Ellis & Every[5]	do	80	100	13						193	69.37	122.65	121.24	80.57	69.11	99.00	26.53		588.47	3.05	1	35	3
Ellis, W. H	do	20	59							79	15.22	55.82	22.41	41.96					135.41	1.71	(6)	10	
Galton, W. W	do	52	6	10						68	29.21	74.41	26.65	72.70	43.64	39.39	9.25		295.25	4.34	1.5	35	2.5
Galton, H. E	do	23	39	13						75	54.35	27.27	7.57	87.48	5.77	63.82			246.26	3.28	2	55	4
Grande, A	do	15	55	15						85	4.25	40.39	64.63	30.73	26.39	43.89			210.28	2.47	1	25	2
Hagerman, J. J.[7]	do	250								250				179.30	110.49	76.01	33.79	153.48	553.07	2.21	Seed.		
Hamilton, W. H	do		60		12					72	99.95	30.33	71.44	57.63	51.72	18.48			323.55	4.46		40	
Hess, J. M	do	5	5							10	9.08	12.67	12.01	11.74	13.50	17.25			76.25	7.62	2.5	35	
Krull, A	do		10							10			17.14						17.14	1.71		15	
Keath, J. C.[8]	do													4.14					4.14				
Do	do	17								17		22.95		14.25	16.38	16.25	11.64		81.47	4.79	1		
Madril (Pecos I. & I. Co.)	do		35	2						37			15.23	30.11	6.69	70.35	20.82		143.20	3.87		28	2
Mihlfied, Jno	do		6	3						9		4.11	2.19	3.88	8.23				18.41	2.05	4	28	2.5
McKenzie & Horton.	do	38	200	10						248	33.51	34.37	139.54	92.47	165.27	168.22	66.60		699.98	2.82		33	3
Otis (town)	do							50		50		16.31				13.72			30.03				
Pinkerton & Galton.	do		60				2			62			51.73	6.78	19.82	11.96			90.39	1.45		35	
Rarey, J. F	do	10	75	6						91	31.65	138.09	69.38	163.59	30.10	111.83	92.50		637.14	7.00	1.25	40	5
Stone, Miles	do	10								10	12.89	13.39		12.06	8.67		11.73		58.74	5.87	2		
Santa Cruz, Felix	do	2	4	4						10	.99	7.23	7.93	6.79		10.78			33.72	3.37	(6)	25	3
Scoggins, Ed[9]	do	3	40	6					[10]15	64		40.19	19.41	20.16	36.90	48.10	10.35		175.11	2.74	1	40	3
Stokes, J. W	Sandy	25	20	5		10				60		38.88	25.38	16.88	31.21	29.89	30.72		172.96	2.88	3	30	3
Salgado, B	Adobe	15	45							60		32.73	51.21	16.69	4.66	54.69	9.17		169.15	2.82	(6)	25	
Stokes, M. K.[11]	do								60	60	34.69	16.72	37.25						88.66				
Stobaugh, J. A	do	18	40							58	6.76	118.35	8.85	20.51	44.88	54.12	11.18		264.65	4.56	2	35	
Skeats, E. M.[12]	do	70	40							110	87.76	132.27	44.70	159.66	44.72	132.18	149.87	53.04	804.20	7.31	2.25	25	
Toone, Mrs. J. B	do	15	25							40	32.39	63.54	26.52	10.39	46.67	49.43	8.38	5.07	242.39	6.06	3	28	
Tedford	do		35							36		.63	23.87	34.88	11.27	21.32			91.97	2.55		40	

Van Kleck, H	do	......	232	5	...	...	1	...	....	237	......	52.95	199.38	3.80	4.63	156.80	75.62	......	493.18	2.08	......	30	2
Wright, Mrs. C. H.	do	10	35	5	...	...	...	...	....	50	8.67	24.55	21.44	2.85	42.41	8.53	......	......	108.45	2.17	3	40	3
Wilson, W. B.	Varied	55	5	7	...	...	...	...	....	67	......	22.84	......	27.53	......	6.55	22.36	......	79.28	1.18	......	....	....
Total		2,106	1,791	250	12	72	25	50	75	4,381	890.54	2,717.89	2,892.96	2,470.30	1,663.43	2,656.16	1,589.55	462.00	14,842.83	3.39	......	....	....

[1] Some alfalfa pastured, not estimated.
[2] Alfalfa pastured.
[3] New land.
[4] Fruit trees dying.
[5] Alfalfa, new.
[6] Pastured.
[7] Was in bad condition.
[8] No crop.
[9] Has bees; doing well.
[10] Sweet clover.
[11] Some alfalfa on land.
[12] Alfalfa dying from too much water.

Acreage of crops and water delivered for the season of 1900, division No. 3, Pecos Irrigation and Improvement Company.

Name.	Soil.	Acreage of crops.										Water delivered, acre-feet.									Depth of water.	Yield per acre.		
		Alfalfa.	Corn.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Grass.	Total.	March.	April.	May.	June.	July.	August.	September.	October.	Total.		Alfalfa.	Corn.	Cane.
																					Feet.	Tons.	Bush.	Tons.
Antone (Pecos I. & I. Co.).	Adobe	4	28	8							40	19.82	21.89	46.83	27.95		46.78	21.79	4.96	190.02	4.75		18	2
Anderiverth	Sandy		20		3						23	4.06	4.81	7.30	7.36	7.57	9.52		3.51	44.18	1.92		18	
Bolles, R. J	Adobe	25	200	5							230		122.01	25.58	24.63	10.85	157.32			339.89	1.48	1	20	3
Beeman, C. W	Sandy	2	40	8			1	1			52		20.80	15.61	55.18	24.39	46.30			162.28	3.06	(1)	25	5
Beet Sugar Co	do												53.31	3.62						56.93		(2)		
Calvani, T	do	5	90	4			.5				99	33.28	36.56	35.80	46.89	35.54	38.07			226.12	2.27	2	28	2
Crowder, O	do	8	25	3			1				37	9.08	16.92	35.98	6.93	49.80	10.63	30.45		159.79	4.32	1	28	
Calderon, A	Adobe		140	15			2	2			159	26.02	80.89	29.82	61.31	122.04	111.64			431.72	2.71		15	2
Cardenas, M. (Pecos I. & I. Co.).	do	30									30			25.06	9.71	13.98	18.89	15.81		83.45	2.78			
Dunnaway, J. F	do	50	55	20							125	96.02	54.46	22.71	36.94		124.90	33.31		368.34	2.95	1.5	20	3
Dishman, C.[3]	do	9					1				10			7.13	6.07	1.17	17.64			32.01	3.20		30	4
Green, C	do	20	57	5				1			83			66.15	22.82	39.21	20.82	59.85		208.85	2.52	2.5	28	2
Gomes (Beet Sugar Co.).	do	35	70				2	1			108	36.29	61.85	41.97	49.28	11.92	44.60	12.39		258.30	2.39	1	13	3
Hughes, Sam	do	30	40		1						71		45.23	43.45	22.91	22.57	37.35	8.38	3.84	183.73	2.59	1	18	
Hagerman, J. J	do	80	40								120				50.97		65.22		15.23	131.42	1.10	.5		2
Gray, E. McQueen	Sandy	25	20		25			2	5		77	60.90	20.84	24.51	50.90	18.04	28.29	12.45		215.93	2.80	2.5	30	
Harkey, D. R	do	8	17	5	3		1		1		35		35.45	2.48	4.34	23.79	18.68			84.74	2.42	1	30	3
Kemp, D. L	do	55	20	5							80	29.28	42.18	39.50	28.53	71.75	116.97	46.79		375	4.69	2	30	3.5
Kahman	do	12	60		3						75	15.22	71.63	27.88	52.16	87.09	7.61			211.59	2.82	1.5	20	3
Lockhart, Joe	Adobe	12	20	8							40			4.84	10.90	10.84	60.26			86.84	2.17	(1)	15	2
Mayes, Mrs. J	Sandy				10						10			4.96	4.11	11.53	4.96	7.43		32.99	3.29			
Nolte, William	Adobe	18	20								38	12.97	33.11	25.71	14.69	28.19				114.67	3.02	2	15	2
Nolte, C	do	6	30	3							39		60.04		53.10			11.42		124.56	3.19	(1)	7	
Niemeyer, F. H	do	12	14		3						29		5.27	7.76	7.83	4.12	8.86		7.43	40.77	1.41	5	20	
Nymeyer, J. O	do		80								80		21.26	12.14	19.71	16.85	16.85			86.81	1.09		40	
Ocon, C	Sandy	8	25			1		1			35		41.51	3.82	7.61	46.30	32.49	26.64	6.22	164.59	4.70	1.5	18	3
Ramuz, A	Adobe	26	30	10	3	1	1	1			72	29.02	64.90	10.16	30.94	63.36	45.11		18.63	262.12	3.64	1	18	2
Smith, Earl	do		16	4							20		1.30	12.26	10.96		17.35			41.87	2.09		20	3
Smith, G. W	do	15	35	5	4	1					60		34.89	29	37.15		31.07	18.68	11.18	161.97	2.70	1	30	4
Stamp, B	do		30	10							40		14.22	12.55	18.54	15.32	14.59			75.22	1.88		15	3
Valles (Beet Sugar Co.).	do	8	40	10			1.5				59	60.13	54.23	57.86	25.79	42.18	37.08	12.45		289.72	4.87		13	2
Stamp, Mrs. M. S	Sandy	No crop.											4.57							4.57				
Webster, G. H	do	85	35		25				3	25	173	35.88	87.96	31.30	66.78		21.78	20.06		264.76	1.53	(1)	20	

Weaver, N.W.	Adobe	....	25.	3	11	....	....	....	....	....	39	......	3.57	......	1.40	......	......	......	......	4.97	......	......	10	4
Florence (town)[4]	Sandy	....	......	....	....	....	....	....	35	....	35	......	......	......	......	......	......	......	......	......	......	......	......	......
Total	....	588	1,322	131	91	3	11	9	44	25	2,225	468.95	1,115.66	713.74	873.89	727.90	1,211.63	337.90	71	5,520.67	2.48	......	......	......

[1] Pastured. [2] Planted. [3] Bees; good crop honey. [4] No record of water kept.

Acreage of crops and water delivered for the season of 1900, division No. 4, Pecos Irrigation and Improvement Company.

Name.	Soil.	Acreage of crops.									Water delivered (acre-feet).								Depth of water.	Yield per acre.		
		Alfalfa.	Corn.	Cane.	Orchard.	Garden.	Beans.	Trees.	Grass.	Total.	March.	April.	May.	June.	July.	August.	September.	Total.		Alfalfa.	Corn.	Cane.
																			Feet.	*Tons.*	*Bush.*	*Tons.*
Cadwell, Edw	Adobe	5	1	1		1.0				8				2.74	4.16	7.33		14.23	1.78	2.0	30	3.0
Bowker, H. D.[1]	Sandy	30	18		10				62	120	51.53	84.54	45.08	34.48	46.59	16.65	27.95	306.82	2.56	2.0	40	
Dishman, C. H.	Adobe	2	10		1		1.5			14.5		8.27	23.65	17.68	16.45	23.01	18.63	107.69	7.43	2.0	35	
Fletcher & Eakin	Sandy	15		15						30	18.50	9.36	4.08	14.09		35.69		81.72	2.72	Past'd.		4.0
Gleghorn, V. V	Adobe		26			.5				27		11.46	10.23	7.98	17.30			46.97	1.74		40	3.5
Hare, W. H.[2]	do				18					18		3.12		2.38	8.32	12.17		25.99	1.44			
Humaston, B	Gypsum		7	1	1	.5				9.5	18.75	17.35	1.83	1.20	1.55	7.93		48.61	5.12		10	
Hakes, E		8	20	2	1	.5			3	35		10.91	6.15	7.40	7.51			81.97	.91		30	2.0
Hoag, L. N.[3]	Sandy	7	20		27		3		6	63	12.18	36.20		29.25	51.62	17.76		147.01	2.33	1.5	20	
Hays, J. W	do		20	5						25.5		3.80	7.37	7.76	15.43	13.16		47.52	1.86		50	4.0
Montgomery, R. A	Adobe	3	30			.5				33.5	5.62	22.78	13.64	18.04		15.41	7.06	82.55	2.46	2.0	40	
Usser, S. H	Sandy		1	8		.5				10			2.26	5.73	4.16			12.15	1.22		30	5.0
Ward, W. W	Adobe	4	8							12	9.08	9.09	10.73	10.61		11.70	9.62	60.88	5.07	New.	35	
Malaga								40		40												
Total		74	161	32	58	3.5	4.5	40	71	446	115.66	216.88	125.02	159.34	173.09	160.81	63.26	1,014.06	2.27			

[1] Grass land irrigated and pastured.

[2] Some trees dying; apples good.

[3] Orchard dying; bad.

Summary.

	Division No. 1.	Division No. 2.	Division No. 3.	Division No. 4.	Total.
Area irrigated ....acres..	1,593.50	4,381.50	2,225.00	446.00	8,646.00
Water used ....acre-feet..	7,409.03	14,842.83	5,520.67	1,014.06	28,786.59
Depth of water used in irrigation..........feet..	4.65	3.39	2.48	2.27	3.33
Depth of rainfall ....do...	1.00	1.00	1.00	1.00	1.00
Depth of irrigation and rainfall.....do...	5.65	4.39	3.48	3.27	4.33

The rainfall given in the above table is the record at Roswell. While this is not exact for Carlsbad, it is approximately correct. More rain fell in division No. 1 than in the other three divisions.

There was a small acreage of Indian corn in division No. 1. Head corn fodder yields 2 to 4 tons per acre, and is worth $3 per ton delivered. There was also a small area of Indian corn in division No. 2. Head corn in this division yielded 2 to 4 tons of fodder per acre, worth $2 to $3 per ton. Division No. 3 received good rains early in the season, but not so much rain fell as in division No. 1. Head corn in this division yielded from 2½ to 4 tons per acre, worth $2 per ton in the field.

The measurements given above are from the records of water delivered to irrigators, and the results may be called the net duty of water. The water flowing through the Pecos Flume to the lands on the southerly side of the river was measured from April 1 to October 27. This does not include the entire period of use, as shown by the tables given above, but will show in general the gross duty, or the water which must be supplied by the river in order that the consumer may get the quantities of water which he used this year. The water passing through the flume serves all of the land in divisions Nos. 2, 3, and 4, and 78 per cent of the land in division No. 1. In the discussion which follows it is assumed that that part of division No. 1 which is below the flume used 78 per cent of the water delivered to that division. The following table gives the daily flow of water through the Pecos Flume:

Water discharged by flume across Pecos River, season of 1900.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1..............	201.2069	320.6330	297.2547	458.6783	303.0260	471.1524	94.1341
2..............	197.9947	320.3190	299.2473	450.2384	320.6880	463.6021	88.857
3..............	212.7486	318.1545	297.7418	449.4094	375.7074	372.7470	96.578
4..............	251.5918	318.4636	306.9239	452.7272	378.4591	278.6721	99.7652
5..............	253.7566	311.0323	338.3448	451.0767	369.3567	247.3681	98.9273
6..............	250.6476	312.3167	369.7929	448.5876	362.9379	222.3403	72.5232
7..............	249.9913	322.0747	371.7746	441.9528	359.2647	177.2234	95.6170
8..............	247.6535	328.1984	384.0346	487.5534	345.5946	147.2991	91.4963
9..............	252.3419	329.7577	398.1740	514.6969	339.5160	178.3065	86.2187
10..............	254.0411	329.2382	390.9893	496.4027	338.5684	177.8425	85.4088
11..............	246.0625	324.6705	408.2265	453.1051	313.2691	176.0607	86.2863
12..............	244.8233	321.6615	432.2794	487.8096	291.1536	210.4164	85.6824
13..............	245.6868	320.7702	431.0657	482.5661	291.5508	236.1497	83.4615
14..............	236.0544	270.7051	402.9110	470.1929	289.2685	232.6022	67.4476
15..............	223.0534	250.5531	403.3623	483.4297	287.8807	225.7542	64.9129
16..............	223.8810	242.0047	402.2298	588.8793	316.7382	223.0529	63.2735
17..............	218.9217	165.6926	406.4279	511.8174	332.7880	223.9425	70.4594

Water discharged by flume across Pecos River, season of 1900—Continued.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
18	214.9935	163.7039	442.7128	504.0843	359.4636	221.8688	72.7200
19	218.7477	184.0896	455.8726	499.6207	389.6833	223.1733	73.6965
20	225.7518	187.1337	474.1916	....	428.7832	217.5020	72.9837
21	239.7910	188.1477	464.2977	....	471.1524	221.7900	70.2012
22	257.9333	189.5933	444.6915	....	469.4666	227.0675	81.8626
23	260.1064	190.9561	447.9976	....	470.1917	186.1178	85.9484
24	263.7568	210.0616	461.2733	....	474.5364	129.1689	85.4068
25	268.5452	243.4668	458.3182	....	473.5672	100.0470	83.3982
26	309.3930	82.1447	459.9916	....	470.4300	109.9878	72.7457
27	312.4191	249.7094	458.1999	....	469.4642	112.3707	29.3861
28	312.8263	244.6299	457.0077	78.1496	469.5847	106.6296	....
29	314.5632	229.9272	456.8880	211.4783	469.7052	103.6368	....
30	315.7942	230.2020	463.8279	189.2153	471.5160	98.4410	....
31	....	250.7070	....	205.3757	458.1401	....	....
Total	7,525.0806	7,950.7187	12,286.0487	9,817.0474	11,961.4523	6,322.3333	2,159.4008

Gross duty of water under Pecos Flume, 1900.

Area irrigated	acres	8,296.00
Water used	acre-feet	58,022.08
Depth of water used in irrigation	feet	6.99
Depth of rainfall	do	1.00
Depth of irrigation and rainfall	do	7.99

The average depth of water delivered to the land below the Pecos Flume from April to October, inclusive, as shown by the records given above, was 3.01 feet, while enough water flowed through the flume to cover the same land to a depth of 6.99 feet, showing that more than half the water flowing through the flume was lost or wasted. The following table compares the volume delivered to the volume passing the flume for each month of the season covered by both records:

Percentage of water entering canal delivered to consumers.

Month.	Discharge of flume.	Water delivered.	
		Quantity.	Discharge of flume.
	Acre-feet.	*Acre-feet.*	*Per cent.*
April	7,525.08	5,130.89	68
May	7,950.72	3,867.92	49
June	12,286.05	4,486.04	37
July	9,817.05	3,169.65	32
August	11,961.45	5,142.95	43
September	6,322.33	2,402.25	38
October	2,159.40	733.76	34
Total	58,022.08	24,933.46	....
Average	....	....	43

While the losses of water have been very large this is not so serious a matter as it would be in many localities, because the farmers have had all the water they wanted.

The past year was the most successful, from the farmer's standpoint, ever experienced in the Carlsbad district. Rains came at opportune times and in quantities not to destroy or impair the works. The raising of sugar beets was abandoned and corn and hay raised

instead. Good crops prevailed, and stock feeding (a comparatively new industry here) made a good market for the farmers' surplus products. As a consequence, there is more demand for land and water, and prices of land have increased about 25 per cent, and a number of sales have been made at the increased price. The experimental stage seems to be passing, and farmers, knowing what is best adapted to this section, are profiting by such knowledge and planting profitable crops, and are succeeding.

WATER USED ON J. J. HAGERMAN'S RANCH, 1900.

Measurements of water used on the ranch of J. J. Hagerman, begun in 1899, were continued in 1900. The record began with April 1, although water was used previous to that time, as shown in the general table for division No. 1 (p. 72). The following table shows the daily use of water on this ranch as recorded at the measuring weir on the lateral supplying the farm:

Water used on J. J. Hagerman's Ranch, season of 1900.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	6.0940	7.2708	4.7243	6.7866	3.1670	4.6104	3.2257
2	7.0152	6.9296	4.8348	7.9296	4.7347	4.8348	3.0270
3	7.1633	6.6951	4.6460	7.7964	5.9511	6.1023	3.0094
4	6.4900	6.4053	4.2340	7.7964	6.5892	5.5326	2.2334
5	5.3585	7.0144	2.3150	8.2436	6.6102	4.4652	.3459
6	5.8545	6.7365	1.5516	8.3340	7.2724	3.7826	.0264
7	6.5685	6.5892	1.5516	4.0314	7.5312	3.9070	.2268
8	6.1153	6.8637	1.0740	....	7.5312	5.3751	1.4632
9	6.9493	6.5682	.0948	....	7.7964	5.3752	2.6638
10	7.2493	6.0549	.6031	....	7.7964	4.3092	2.7731
11	6.5694	5.5712	.9214	....	6.7881	3.3177	2.8196
12	6.8424	5.3041	.7960	....	6.2568	3.1497	2.8990
13	7.0132	6.7161	.9651	....	6.8211	3.7476	3.1265
14	6.9489	7.5276	.9096	....	6.5892	3.7476	3.2229
15	6.9706	5.7012	.9204	....	6.3189	3.8351	3.1404
16	6.4638	4.5201	.8160	....	6.7572	3.7456	3.1404
17	6.0532	2.3267	1.0904	....	6.9489	4.0644	3.1404
18	6.2375	1.5421	1.1469	5.1536	6.6732	3.9594	3.1404
19	6.6942	1.0340	1.0309	8.4475	6.5878	3.3384	3.1404
20	6.6942	2.0705	.9871	7.7641	6.2568	3.2724	3.8640
21	6.7572	3.2130	.8895	1.3037	6.6102	3.6106	3.9422
22	6.5907	4.3413	1.3219	....	6.5052	5.0934	3.3722
23	7.0128	4.9721	2.2189	....	6.5472	4.1140	3.5412
24	6.9489	3.6299	4.5351	....	6.5262	1.2708	3.2732
25	6.7161	3.2229	5.7102	....	6.1752	.7429	3.1404
26	6.5052	1.6983	6.0936	....	6.3422	2.7226	3.0918
27	6.5052	3.1910	6.2574	....	6.1538	3.3561	1.3321
28	6.4224	4.3941	7.2801	....	5.4158	3.2068	....
29	6.8220	3.6046	6.6341	....	4.7226	3.2952	....
30	7.1634	2.9460	4.1712	....	4.1902	3.4406	....
31	....	2.6060	....	.9682	4.2986	....	....
Total	198.7882	147.2605	80.3250	74.5551	193.2650	115.3253	72.3218

Duty of water on J. J. Hagerman's Ranch, 1900.

Area irrigated	acres..	90
Water used	acre-feet..	881.8409
Depth of water used in irrigation	feet..	9.80
Depth of rainfall	do...	1.00
Total depth of water received by land	do...	10.80

ARIZONA.

IRRIGATION IN THE SALT RIVER VALLEY.

By W. H. CODE, *Special Agent.*

INTRODUCTION.

The Salt River Valley was selected as the most favorable agricultural section of Arizona in which to carry on investigations regarding the condition of irrigated agriculture, and the writer was requested to act as special agent in the compilation of the data so obtained. A report was submitted last year (1899)[1] showing the duty of water under the Mesa Canal, and it was the intention, for the purpose of the present report, to extend the investigations so as to include the entire valley. Unfortunately the unusual drought and low stage of water in the river for the past year have made it impossible to use water as it should be used to obtain the best results, and for this reason the recorded data of flow hereafter submitted are of little value in determining either a proper duty of water or the results which would come from such use.

The acreage given under each canal is therefore smaller for this season than it would have been in ordinary years, as there was less grain put in on the newer lands under each of the systems than is the general custom, and in many instances alfalfa land was almost entirely deprived of water in order that the farmers might keep their vineyards and orchards from suffering. This unusual season, while it has entailed some hardships on the citizens of the valley, has not worked entirely to their disadvantage, as the farmers, merchants, and professional men, one and all, have had brought home to them the necessity of an increased and constant water supply, and are united in the effort to obtain it.

GENERAL DESCRIPTION OF THE VALLEY.

The Salt and Gila river valleys, which to all appearances comprise one vast mountain-locked basin, are estimated to contain over 1,000,000 acres of irrigable land, a large portion of which could be reclaimed if our flood waters were impounded by means of storage reservoirs on the Gila, Salt, and Verde rivers. This vast area of fine alluvial soil

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

has latent possibilities almost beyond comprehension, which will undoubtedly some day be realized by the development of our underground supply and the conservation of the waters now allowed to waste down the various streams above mentioned to the sea.

SOILS.

The soil of the Salt River Valley, when properly irrigated, produces large yields and a great variety of products. Even the virgin desert, when watered and sown or planted for the first time, gives excellent results, though not so satisfactory as those obtained from the seeding of what is known as "old alfalfa ground." It has been practically demonstrated many times by the farmers throughout the Salt River Valley that the soil's first requirement, no matter what is to be subsequently raised thereon, is a good growth of well-rooted alfalfa as a foundation. The results of this practical experience of our farmers is corroborated by the laboratory investigations of Prof. Robert H. Forbes, of the Arizona Experiment Station. He has published the results of a thorough and comprehensive study of the soils of the valley, his summary, based on the data contained therein, being as follows:

(1) The soils of the Salt River Valley, generally speaking, are amply supplied with the more essential mineral-ash plant foods, including lime, potash, and phosphoric acid.

(2) Nitrogen and humus are undoubtedly deficient in quantity, and the addition of these soil ingredients is desirable, perhaps imperative.

(3) Alkaline salts are not prevalent in excessive amount except in occasional localities of limited area. The alkali is very "white" in character, and consequently its injurious effects are minimum.

(4) Probably the most serious difficulty with our virgin soils is a physical one. Their dense, compact condition must be remedied by suitable methods of culture.

(5) The cheapest and best methods of supplying the lack of humus and nitrogen and improving the tilth and water-holding power of these soils is by growing leguminous crops upon the lands and plowing them under as green manures. So far as now known, alfalfa and crimson clover are the best of these, and their use for this purpose is undoubtedly an essential part of any scheme of crop rotation for this region.[1]

As a rule, the higher mesa lands are free from alkaline salts, at least in such quantities as to render them harmful, but on the lower-lying lands adjoining the river there are occasional areas containing an excessive quantity of "white" alkali. With the construction of proper drainage canals I presume the salts can be leached out and the lands rendered as productive as any. Mr. Thomas Means, of the Division of Soils of this Department, has made a survey of our valley during the past few months, carefully locating such strips of alkaline lands on maps, and it is to be hoped that the knowledge so gained

[1] Arizona Station Bul. 28.

FIG. 1.—CATTLE IN ALFALFA FIELD.

FIG. 2.—DATE PALM GROWING AT PHOENIX, ARIZ.

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may induce a further study, with a view to planning a comprehensive system of drainage for such areas, for notwithstanding the fact that they may be few in number, each tract is a blot on the landscape and detracts more or less from the value of the contiguous farms.

PRODUCTS.

As before stated, the irrigated land of the Salt and Gila river valleys produces a great variety of crops. Among cereals wheat and barley take the lead, although rye, oats, and corn can be raised successfully. Alfalfa is king of forage plants in Arizona, and sorghum is next in importance as regards luxuriance of growth. These two crops, the former especially, have rendered possible the great success of our cattle industry in the valley. (Pl. VI, fig. 1.)

Vegetables of various kinds, melons, and berries all thrive well, the latter two having especially long seasons.

Of fruits we have many kinds—the orange, pomelo, olive, date (Pl. VI, fig. 2), apricot, peach, pear, fig, nectarine, pomegranate, and plum. Of grapes the following are some of the varieties found here: Muscat, seedless Sultana, Lady Downing, Flaming Tokay, and Thompson seedless. The last-named grape is especially adapted to the soil and climatic conditions of this section and is rapidly growing in favor.

The past season has been an unusually encouraging and profitable one for orange growers throughout the valley. Many sales of young groves and orange lands have been consummated as a result of the showing made. The fact that our oranges can be placed on the Eastern markets several weeks earlier than those of California gives us a great advantage in this branch of horticulture.

Almond culture is also attended with a large degree of success, there being some uncommonly fine orchards in the vicinity of Mesa, which, though young, are productive and profitable.

Poultry raising, bee keeping, and dairying are all prominent industries, the last being the most important and lucrative, owing to the favorable climatic conditions, which enable dairy cows to graze throughout the whole year at a minimum cost to the owner.

IRRIGATION SYSTEMS.

The valley is well supplied with irrigation systems, some 300,000 acres of irrigable land being covered. Since, without reservoirs, there is not sufficient water to irrigate more than half of this area, it will be seen that there is no crying need for more canals at this time. The following table gives the names, sizes, lengths, etc., of the main canals of the Salt River Valley east of Phoenix. There are other quite important systems west of Phoenix, but they do not enter into the scope of this year's investigations.

Irrigation canals of Salt River Valley east of Phoenix.

Name of canal.	Total length of main canal.	Maximum bed width near head.	Average slope per mile.	Maximum capacity.	Water first appropriated.
SOUTH SIDE.	*Miles.*	*Feet.*	*Feet.*	*Cubic feet per second.*	*Year.*
Highland	22	18	1.50	75	1889
Consolidated	38	45	2.25	1,000	1891
Mesa	3.5	18	2.00	175	1878
Utah	10	18	2.50	150	1877
Tempe	32	28	2.50	325	1871
San Francisco	12	9	2.50	50	1871
NORTH SIDE.					
Arizona	47	44	2.00	1,000	1885
Grand	27	22	(1)	215	1878
Maricopa	26	22	(1)	250	1868
Salt River (joint head)	19	....	(1)	....	1868

[1] Variable.

Previous to the year 1885 the water of the Salt River was allowed to find its way down a wide sandy river bed to the various canal heads situated along its banks for a distance of about 20 miles. The canals heading lowest down the river channel, as usual, were the ones entitled to the larger appropriations, and when the water became scarce the constant anxiety of the farmers under these canals was to see that their neighbors above allowed their full supply of water to reach them. Since there was no water commissioner at that time whose duty it was to see that each canal received its portion of water regardless of location, or rather, since there had been no adjudication to determine their rights, it can be easily imagined what unsatisfactory conditions prevailed. Each canal owner looked upon every other as his natural enemy.

The construction of the Arizona Canal solved the problem of economical distribution for the canals on the north side of Salt River, as it finally diverted the waters of the old systems—Salt River, Maricopa, and Grand—at a point about 18 miles above their original headworks, conveying it in a canal some 22 miles, then returning it to them by means of a crosscut canal. The Maricopa and Salt canals still maintain a joint or consolidated head, however, in order that they may be assured a more abundant supply in times of high water. During the seasons of low water they are supplied through the Arizona Canal, with the exception of about 60 cubic feet of water per second which, for the most part at least, is the result of seepage from the irrigated lands above.

While the advent of the Arizona Canal radically changed the system of delivery on the north side of the river, the conditions on the south side remained practically as they had been until the construction of the Consolidated system, on which work was begun in 1891. The head of this canal is some 4.5 miles below that of the Arizona Canal, and on the south side of the river. It is built sufficiently large to carry all of the water which the south side canals are enti-

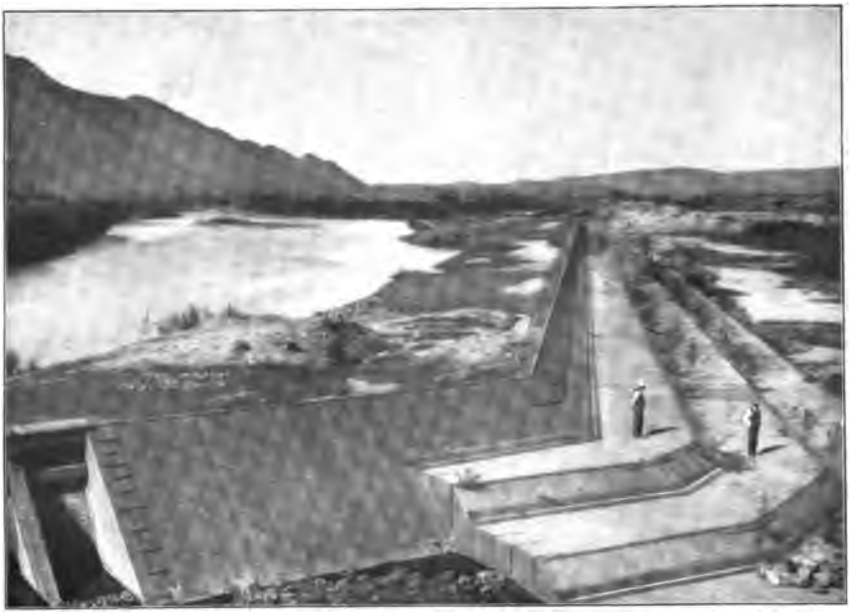


FIG. 1.—DIVERSION DAM, ARIZONA CANAL, LOW WATER.

FIG. 2.—DIVERSION DAM, ARIZONA CANAL, HIGH WATER.

tled to receive in ordinary stages of the river, and effects a great saving of water by so doing. Previous to its construction, the water of the Tempe Canal was allowed to flow down the river, passing through a wide sandy section of the channel some 7 miles in length. This portion of the river bed seemed to absorb water like a sponge, and frequent measurements by different engineers determined the fact that in the summer season especially there was a great waste of water between the dam of the Tempe Canal and that of the Consolidated system located about 7.5 miles farther up the river. The Consolidated Canal Company, in constructing its canals, planned to carry the water of the Tempe Canal in its waterway and make an intermediate use of the water for power purposes by turning it over a 40-foot bluff, through a power house, and subsequently into the Tempe Canal, which parallels the base of the bluff in the vicinity of the power plant. The Consolidated Canal Company further claims the right to the saving effected by taking the Tempe water into its canal instead of allowing it to flow down the river channel as in former times. Its right to the intermediate use of the Tempe water for power purposes was confirmed by the courts, and it has been using a good portion of the minimum flow for several years in pumping water and operating electrical machinery, but its right to any specific amount of saved water has not yet been determined.

The water of nearly all the canals of the valley is therefore delivered to them by means of two large systems—the Arizona on the north side of the river, and the Consolidated on the south. The Arizona system in seasons of low and medium supply intercepts the entire flow of Salt River at its dam (Pl. VII), with the exception of the several hundred inches of seepage water which leaks under the dam, and carries this volume in its canal for a distance of about 4 miles, turning that portion of it belonging to the south side canals back into the river channel at a point immediately above the dam of the Consolidated Canal Company. A crosscut canal has been recently built by the Arizona Water Company from its main canal to the edge of the river bluff (fig. 12), and at this point the company contemplates the erection of a water-power plant in order that it may make intermediate use of the south side water supply for power purposes. The Consolidated Canal Company in turn intercepts the water thus turned to it, which includes the combined supply of the Tempe, Mesa, and Utah canals.

The water of the Utah system is carried a distance of only 2.5 miles, and is then turned back into the river channel through wastegates located about one-half mile above the Utah dam. The supply of the Mesa and Tempe canals is brought down a distance of 8 miles from the headgates to a point known as the Division Gates. Here the Mesa water is delivered to the Mesa Canal proper, and the Tempe supply turned westward through the Consolidated Crosscut Canal, leading

to their power plant before mentioned, where, after an intermediate use, it is turned into the Tempe Canal.

LAWS CONTROLLING WATER DELIVERY.

The water distribution of the Salt River Valley is under the control of the judge of the local district court, who appoints a water commissioner to represent him in the actual duties of the office. There have been no legislative enactments as yet in Arizona for the purpose of Territorial control of the water supply within its borders, and the need of such laws is becoming more apparent each year. It is hoped by many that the coming legislature will take some action along this line, as each year's delay causes more complications which will have to be adjusted subsequent to the enactment of a general Territorial law. The law under which the canals of the Salt River Valley are

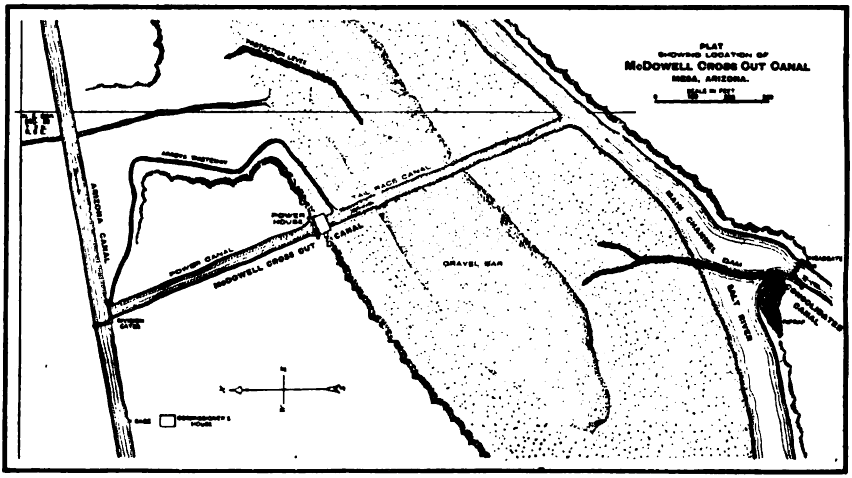


FIG. 12.—Plat showing McDowell Crosscut Canal, Mesa, Ariz.

now operating is known as the "Kibbey decision," given by Judge Joseph H. Kibbey, as a result of a long and exhaustive trial in 1890. Several of the canal companies entered into a certain contract regarding the division of the water subsequent to the suit, and the commissioner is guided somewhat by the terms of this contract during ordinary stages of the river as well as by the decision proper. One of the main objects of this contract between the north and south side canals was to provide that each should receive some water for irrigation of fruit trees and for stock purposes during the low stages of the river, as without this agreement some of the newer canals would have been completely shut out of water during such periods.

Judge Kibbey's decision recognized as the fundamental principle of water rights that priority of actual beneficial application of water to the land gives priority of right to water. In adjudicating the rights of the farmers under the different canals to the water of Salt River

scores of witnesses were examined in order that the dates of the actual application of water to the lands under the canals named in the suit could be determined. From the data thus obtained a table was prepared which showed the amount of water each canal was entitled to receive, based on the number of quarter sections of land reclaimed under the various canals for each year between 1868 and 1889. The duty of water was not arbitrarily fixed in the decision, but the commissioner has been dividing the water on the basis of 64 miner's inches to the quarter section. This decision, as now in force, therefore, establishes only the rights of the several canal companies to take in at their heads certain quantities of water, based on the dates of the reclamation of the underlying lands, and does not attempt to determine the priorities of the individual consumers under each system. As a result, a number of lawsuits have been brought by water consumers under these canals from time to time, seeking to have their individual priorities determined. Judge Webster Street made a most important ruling in February, 1900, selecting four cases out of a large number that had been brought against the several canals on the north side of Salt River. These four cases contained the principal points to be passed on by the court in the many cases pending. A full transcription of Judge Street's decision, together with that of Judge Kibbey, will probably be included in a special bulletin at some future date, so that such brief references as are here made to them are for the purpose of making clearer the present method of water distribution by the water commissioner of Salt River Valley. I will say as regards Judge Street's decision that it does not demand that the waters in the canals of the valley shall attach solely to the old lands under said canals; neither does it affect or change the existing method of distribution by the water commissioner, who is still guided by the table prepared as a result of the decision of Judge Joseph H. Kibbey, which was published in my report for 1899.[1]

DUTIES OF WATER COMMISSIONER.

The present water commissioner, Mr. F. P. Trott, has heretofore lived in Phoenix, making frequent trips over the systems to check up his gaging stations. With telephonic communications and the assistance of a gage rider he was enabled to keep a very close check on the water distribution. He has recently effected quite an important change of residence, having moved up to the new crosscut canal of the Arizona Water Company, at the point of division between the north and south sides of the river before mentioned. The canal companies have combined to construct him a house at this point, and he will be connected by telephone with each of the companies interested in the water division. The gage rider reports to him the morning and

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

evening readings of all his gages, so that he is constantly posted as to the condition of the river, as for his purpose the combined totals of the various canals give the total quantity of water in the Salt River. Thus, knowing the total available supply, he is enabled to calculate readily the number of inches each canal is entitled to receive, and, by telephoning, to order any headgate opened or closed on short notice. He keeps a careful record of the daily average flow of each canal and the river, and has done so for the past five years, or during the period of his incumbency to date. His salary, together with that of the gage rider, is paid by the canal companies of the valley, each being assessed at the end of every month.

Gaging stations are located in all of the canals, generally a few miles below the headgates, at such points as long experience has demonstrated best suited for the purpose as regards uniformity of cross section and freedom from sand or silt deposits. Gages located below wastegates are preferable to those near the heads of canals, as the latter are more liable to error on account of shifting sand deposits. The commissioner keeps a continual check on the different gages, as do other engineers interested in an accurate water division. The writer has had occasion to gage the valley canals many times during the past year in connection with the preparation of this report, and can testify to the general accuracy of the gages.

After the water passes the gaging stations the commissioner is relieved from any further supervision of it, and it is taken in charge by the managements of the different canals, who instruct their zanjeros as to its distribution. Here is largely where our trouble begins with the present method of distribution, the Kibbey decision being only partially carried out. When the water apportioned to the respective canals by the said decision has passed the commissioner's gage, no further jurisdiction is exercised over it by the court or its officers, and it therefore becomes more or less open to manipulation.

The stock of each of the canals on the south side of Salt River, as an example, is divided into a certain number of shares, which shares are not attached to the land in any way, and are therefore subject to barter and sale. A man owning a piece of desert land, absolutely valueless without water, can afford to pay a large price for a share of water, providing he can at once thus place his new land on a par with the oldest land under the canal system. The owner of shares and old land may be tempted by the large price to sell one or more of his shares in the canal to the man with the new land, not realizing apparently that he is aiding in his own downfall by lowering the valuation of his old land to that of a virgin desert. The fact that water shares are increasing in value of necessity means but one thing, viz, that the value of land is proportionately decreasing, since the value of an acre of alfalfa with the necessary water remains fairly uniform. The tendency of the present method, therefore, is evidently

to spread our water over a greater area than it will properly irrigate, and the need of some definite and immediate legislation is apparent to all who are familiar with the existing conditions. Fortunately, to date the fear of the ultimate carrying out of the doctrine of prior rights and of attaching the water rights to the land has prevented to a great extent excessive reclamation of new lands.

INCREASING THE WATER SUPPLY.

The citizens of the valley are united in the determination to increase their water supply, and this bids fair for the future, as a combined effort along this line should accomplish much. We can well emulate the example of our neighbors in southern California, who have shown remarkable courage and energy in water development during the past few years. It is estimated that they have increased their water supply to the extent of 20,000 inches by pumping plants alone, and thus saved thousands of acres of valuable orchards, which otherwise would have perished.

RESERVOIRS.

The plan most generally favored by our citizens for an increased water supply is the construction of a storage reservoir in Salt River a short distance below its junction with a tributary known as Tonto Creek. Nature has contributed a magnificent natural site for a reservoir at this point, the valleys of both Salt River and Tonto Creek above the dam site being wide and well adapted for storage purposes. The surveys made by the Hudson Reservoir Company, which has been working for several years toward the construction of a dam at this point, show that its capacity with dam erected 175 feet above low water would be over 700,000 acre-feet, and at an elevation of 200 feet, 1,020,000 acre-feet. This is a marvelous storage capacity, and is the more remarkable when it is considered that the length of dam proper at an elevation of 215 feet measured on the curve is less than 650 feet. It has a great mountainous drainage area, and in ordinary years there would be an immense quantity of flood water impounded, but our experience of the past year has demonstrated that it would be necessary to maintain a large reserve supply of water in the reservoir in event of its construction to tide us over a season similar to that of 1900. While such a dry period may not occur again in thirty years, yet the fact that it has occurred makes it important that it should be taken into consideration in all plans relating to an increased water supply and extension of our irrigated area. It is hoped that a reservoir may also be ultimately constructed on the Verde River, there being two projects in view to that end. They all represent immense undertakings and large investments of capital, but the advantages that would be derived by the Salt River Valley would be in keeping with the magnitude of the work. There

are great problems to be solved in the successful engineering of a storage dam in either the Salt or Verde rivers, prominent among them being that of planning suitable wasteways for a volume of flood water approximating 150,000 cubic feet per second. The flood of 1891 in Salt River below its junction with the Verde was estimated by local engineers to approximate 300,000 cubic feet per second, a volume sufficient to fill both the Salt and Verde reservoirs in less than two days' time, and should a flood continue for more than this period, necessitating the wasting of a similar volume after reservoirs are full, the magnitude of the task of constructing suitable wasteways is apparent to all who witnessed that memorable flood. It is stated that the larger portion of this great flood came down the Salt River.

Chief among the advantages to be derived from the conservation of our flood waters would be a uniform flow to the canals of the valley in place of the more or less irregular supply of the present time, with such flow regulated according to the requirements of the crops. In average years the canals run sufficient water to the underlying irrigated lands to cover them to a depth of from 3.5 to 4 feet, an amount certainly sufficient to produce maximum crops could it be delivered throughout the year in uniform heads and according to the demands of the crops. The records of the Mesa Canal, as given in my report last year, show that even this system with its limited supply, as compared with the older canals, has averaged a flow during the years 1896, 1897, 1898, and 1899 equal to 3.6 acre-feet per acre irrigated.

The Mesa farmers are compelled to use great quantities of water during the flood periods, in order to tide over months of scant supply, and this is generally true of the entire valley. It is evident that this is far from an economical use of water, and the farmers with this supply, averaging nearly 4 acre-feet during the 12 months, lose from two to three crops of alfalfa. One result of last year's investigation was to show that an acre-foot of water as used at present in diversified farming under the Mesa Canal yielded gross returns ranging from $4 for common farming operations to $30 for almond culture. A crop of grain which matured with 1.98 acre-feet of water, plus 4.39 inches rainfall, gave a gross return of $7 per acre-foot applied. If an acre-foot of water can be made to yield such returns even with our present irregular and uncertain supply, it is evident that it would be largely increased in value could it be delivered throughout the year according to the needs of the crop.

When the great storage capacity of the contemplated Hudson Reservoir is taken into consideration, it seems as though the construction of this dam in the Salt River would be not only the best practical solution of how to increase the water supply for lands already farmed, but the best means of extending our irrigated area so that all the

desert lands covered by our large canals may be reclaimed from their present arid condition.

To fully insure this desirable condition of affairs in the Salt River Valley, however, we should not stop with a reservoir in the Salt River, but should also have one in the Verde, as the latter river furnishes us with a large portion of our water, both normal and flood volumes.

The citizens of the valley at a recent meeting held in Phoenix, appointed a committee of thirty representative citizens to study the many plans brought forward relative to an increased and constant water supply. The committee resolved itself into several subcommittees as follows: Executive, finance, investigation of dam sites, silt deposits, underflow of streams, pumping, and one on the feasibility of diverting a portion of the waters of the Colorado River into the Salt River Valley. While the consensus of opinion of the committee was that this last scheme was too impractical to merit much attention, it was thought best to appoint a committee to examine such data as were available and to make some surveys if necessary in order to satisfy a number of our citizens who cling tenaciously to the idea that the plan is feasible. This subcommittee has already gathered sufficient information to convince most people of its utter impracticability from a financial point of view.

UNDERGROUND SUPPLY.

While it is generally admitted that storage reservoirs are the great desideratum, many of our farmers and horticulturists are investigating the matter of utilizing our underground supply by means of pumping plants. Dr. A. J. Chandler, president of the Consolidated Canal Company, and Mr. Simon J. Murphy, of Detroit, Mich., are at present engaged in boring wells with the hope of getting artesian pressure, and in event of failure to do this, they intend to install pumping plants to raise water from the wells. The Murphy well was started as a 12-inch, double-steel cased one, but on account of the great difficulties encountered in the way of bowlders and cement strata, together with a peculiar formation of clay known as the swelling variety, it has been necessary to reduce the size of the well three times in a depth of 1,305 feet, ending with a casing of 7 inches in diameter. I submit a sketch of this well, showing reductions and character of material encountered. (Fig. 13.)

After the completion of the well it was tested by means of a propeller pump and a traction engine. Owing to the fact that both the pump and engine were of insufficient capacity, the test was not wholly satisfactory or long continued. The showing made, however, was very good indeed, the well yielding 1.5 cubic feet per second after the water was lowered in the 12-inch casing to a depth of 6.5 feet below normal level. The water stood at a depth of 28 feet below surface level of ground before pumping operations began. This test is greatly in favor

of the deep-bored well over the shallow open-dug well, as the volume of flow is greater in proportion to the depth the water is lowered.

There is some doubt as to which strata this water is obtained from, some contending that it comes from a layer of water-bearing material encountered at 612 feet; others, that the flow would be as great had the pipe been perforated no farther down than the 212-foot level. This is an important fact to determine, as the cost of boring increases with the depth. In all probability Mr. Murphy will have several more wells put down soon, and he will then ascertain to a certainty the strata to which is due the excellent supply.

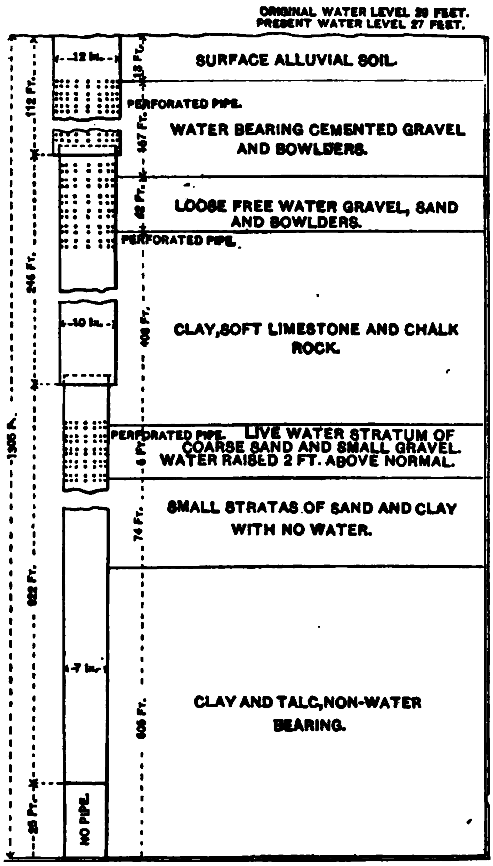


FIG. 13.—Bored well of S. J. Murphy on McQueen Ranch, Mesa, Ariz.

While the cost of water raised from wells is great as compared to that furnished from the river by means of canals, the importance of a supplemental supply is being keenly felt, particularly by our horticulturists. A low stage of water in the river during the early spring and summer months causes a greatly reduced crop of fruit, and from the lack of one or two irrigations the crop in some instances is reduced fully 50 per cent in quantity. While in ordinary years heavy winter irrigations of orchards and vineyards tide over this dry period to a great extent, it is beginning to be felt that there is a necessity of providing some means for obtaining an additional supply as an insurance against occasional seasons of shortage.

The writer has had some experience in the sinking of open wells in Salt River Valley, which may be of value to some horticulturists or farmers who contemplate a similar work. To a man who has not had actual experience with the bowlder and quicksand strata encountered in digging wells in this vicinity, the mere excavation of an open well

may seem ordinarily easy. The Consolidated Canal Company decided to investigate the underground water supply in the vicinity of their water-power plant near Mesa, Ariz. Since it was to be simply an experimental well, it was thought best to construct it in the least expensive manner possible. With this end in view, a contract was given to some miners to sink a well as deep as we should desire, at a stipulated price per linear foot in depth, we to keep the water out of their way and also to furnish the lumber for cribbing the well. The miners proceeded in the manner common in the sinking and timbering of mining shafts, and we kept the water out of their way as per contract. The natural elevation of the ground water was 7 feet below the surface level at the point selected, and for this distance the excavation was in earth. From this depth on the formation was alternate layers of quicksand and bowlders. The well was 8 by 16 feet, inside measurement, and by dint of perseverance in the face of many obstacles, we sunk it to a depth of 23 feet below the normal level of the water. It is needless to enter into detail concerning the trouble and expense connected with the sinking of this kind of a well through the material above mentioned to a depth sufficient to give a maximum

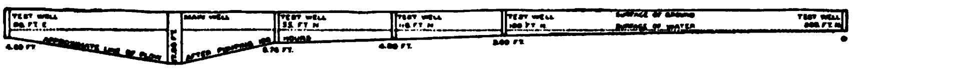


FIG. 14.—Diagram showing water levels before and after pumping from well of Consolidated Canal Company, Mesa, Ariz.

flow of 4 cubic feet per second (160 miner's inches). We were taught by this experience how not to sink open wells, for although this one is still in fair condition after a service of several years, we know it is not a permanent structure.

After the well was sunk as deep as we deemed practicable, the writer made some observations as to the effect of the steady pumping of 3.75 cubic feet per second (150 miner's inches) on the water levels of adjacent wells. Pits were sunk at varying distances from the large central well, and careful levels were taken of the surface of the water in each well previous to the test run, the elevations being found practically the same. The pump was started in the central well and discharged a constant stream of 3.75 cubic feet per second for one hundred and four hours, near the end of which time levels were again taken of the water in the various sumps. The sketch herewith submitted shows the result of the experiment. (Fig. 14.) It will be seen that the water in the large well pumped from was lowered to a depth of 17.68 feet below normal level. No. 1, distant 55 feet, to a depth of 6.76 feet below normal level; No. 2, distant 90 feet, to a depth of 5.94 feet below normal level; No. 3, distant 118 feet, to a depth of 4.90 feet below normal level; No. 4, distant 180 feet, to a depth of 3.50 feet

below normal level; and No. 5, distant 360 feet, to a depth of 1 foot below normal level.

It will be noted that the sump at a distance of 360 feet from the main well was lowered a depth of but 1 foot, and that the steepest cone of depression was that between the main well and test hole No. 1. This data was of use to the writer in subsequent work as consulting engineer on the location and construction of a new well for the Phoenix City waterworks, where the location of an old well and all pumping machinery made it advisable to keep as close to the same as possible. The new well was located a distance of only 80 feet from the original one, and has given an excellent additional supply of water without affecting the supply of the old well as much as might be naturally presumed.

In planning for the new well, which was to be circular and 20 feet in diameter, the caisson principle was adopted and found to work admirably, the workmen excavating under the wedge-shaped shoe in safety and the caisson sinking of its own great weight. (Fig. 15.) The walls were constructed of rubble masonry 18 inches thick, firmly knit together with an interlacing of heavy bolts. A large pit about 25 feet in diameter was first excavated to natural water level, and the timber casing was built in the pit at this depth. The masonry wall was then built on the timber casing to a height of 12 feet and allowed to set firmly. A platform was built across the caisson at this elevation, on which the centrifugal pumps were placed. The workmen then started excavation, the pumps keeping the water out of their way, and in this manner the work continued to a depth of 22 feet below normal water level, and 39 feet below the surface of the ground.

These data are detailed to some extent with the thought that they may benefit some of the valley ranchers and fruit growers who contemplate installing pumping plants. Some of our farmers are excavating large open holes in the hope of getting down sufficiently low below water line without cribbing. This plan may work if the gravel and bowlder formation does not alternate with strata of quicksand. If it does it will be impracticable to attempt it.

Available underground supply.—From such experience as the writer has had in measuring the flow from open wells, he feels safe in venturing the following estimates on available supply: Where the water strata are composed of bowlders, gravel, and quicksand, the common formation, a flow of 4 cubic feet per second may be obtained from an open well about 16 feet in diameter sunk to a depth of 25 feet below normal water level. A flow of 1.87 cubic feet per second should be obtained at a depth not greater than 15 feet below said level.

Approximate cost of well and machinery.—To install a good steam plant of 60 horsepower, with 70-horsepower boiler, including buildings, centrifugal pumps, belts, etc., will cost, approximately, $3,500; cost of

open well, 50 feet deep, 16 feet in diameter, 25 feet below water surface, 18-inch brick walls or timber shoe, $3,500; total cost, $7,000. This plant should develop 160 inches of water. The cost is based on a

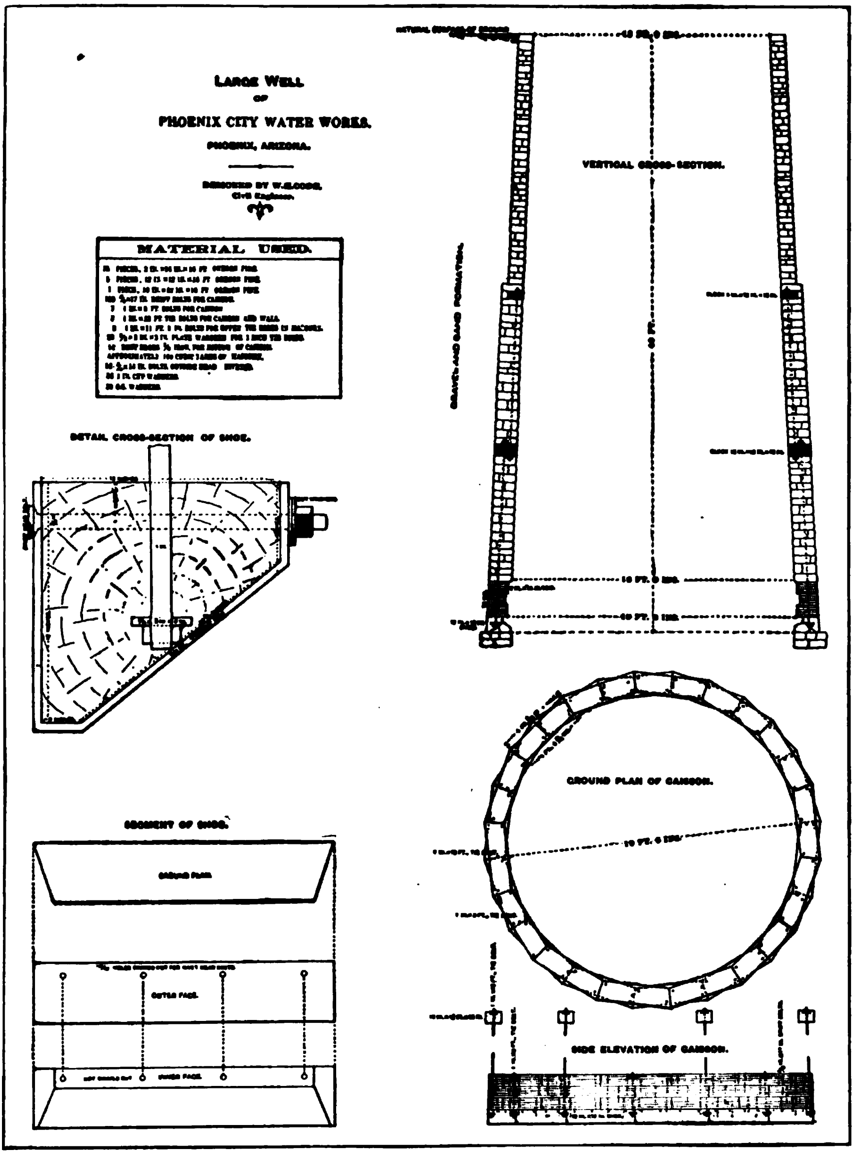


FIG. 15.—Well of Phoenix city waterworks.

50-foot lift. The engine and boiler are calculated of excess capacity for use in event of lowering of underground supply. Owing to the high freight rates between California and Arizona, it is impracticable to consider crude oil for fuel for an engine of above capacity at this

time—at least so I am informed by mechanical engineers who have studied the question. They claim that good mesquite and ironwood, at $4 per cord, is more economical than oil at present prices. They contend, however, that for plants up to 15 horsepower or thereabouts the gasoline engine burning a high-grade distillate is more economical than a steam plant of similar power.

Cost of pumping 4 cubic feet per second with 50-foot lift.—With wood at $4 per cord, the expense of lifting 4 cubic feet per second to a height of 50 feet, including wages of fireman, oil, repairs, etc., will approximate $20 each day of twenty-four hours' run. This flow of water would cover nearly 16 acres to a depth of 6 inches, which is ordinarily considered a fair irrigation. The expense of this irrigation would be at the rate of $1.25 per acre, or $2.50 per acre-foot. Assuming the duty of water to be 4 acre-feet per annum per acre, the cost of pumping for the entire year would be $10 per acre irrigated. It is taken for granted in these calculations that the land pumped for is in close proximity to the well, as otherwise the loss from seepage and evaporation would increase the cost per acre-foot applied.

It is obvious that pumping from such a well would be a very expensive proposition for common farming operations, and this method of obtaining water is not recommended for such farming, or even for horticulture, should there be no supply from canals. The writer contends, however, that on all tracts of land yielding large returns per acre, such as orange, apricot, and almond orchards, vineyards, and melon and vegetable farms, the establishment of the pumping plants as a supplemental supply would not only be practicable but highly profitable should the lift not exceed 60 feet. It would, of course, be important to have water free from alkaline salts in injurious quantities, but such information can be obtained by having a chemical analysis made of the water previous to the establishing of pumping stations.

Where it would be possible for a number of fruit growers to cooperate and put in a large community pumping plant it would perhaps be the most satisfactory and economical method to employ, assuming that the tracts of land to be supplied are in close proximity. It is claimed by some California engineers that water is being raised 35 feet in the San Joaquin Valley by means of direct-connected centrifugal pumps, operated by electricity, at the expense of only 75 cents per acre-foot. If this is the case, it is evident that water-power plants are easily and economically installed in that vicinity, and that electrical power can be furnished at a price not greatly exceeding $40 per horsepower per annum.

Professor Wickson, of the University of California, in a recent bulletin on "Irrigation in fruit growing,"[1] gives the following data:

In Santa Clara Valley, one of the leading fruit regions of central California, there are about 1,500 irrigating plants of all kinds in the valley proper. About

[1] U. S. Dept. Agr., Farmers' Bul. 116.

900 of them have been put in during the past three years. Many of them have centrifugal pumps run by steam. These are the larger plants, where from 15 to 40 horsepower and in some instances more are used, and the size of the pumps ranges from 4 to 12 inches. Most of the smaller pumps are run by gasoline, though several use crude oil, and many of them are also centrifugal. Some of those are deep-well pumps and they are very satisfactory in raising water from a greater depth than 100 feet. From 100 to 500 feet they work admirably.

The cost of pumping differs materially with the different kinds of power, sizes of pumps, and depths of wells. Figuring from what might be a safe average of the actual cost of fuel, a No. 4 pump, centrifugal, with gasoline as power, at 70 feet depth, would cost $3 per day. This would result in 600 gallons per minute, 36,000 gallons per hour, or 360,000 gallons per day of ten hours. Such a stream of water is calculated to irrigate about 5 acres per day to a depth of a little more than 2.6 inches. But these figures being of the best experiments, a better and safer estimate would probably be 4 acres per day to a depth of about 2 inches.

But, generally speaking, it is safe to say that at a cost of about $3 per acre for the water the orchards of Santa Clara County can, under the present process, be irrigated two or three times at $6 to $9 per acre per year. The average cost of plant is about $1,200.

There is some variance of opinion regarding the probable permanency of an underground supply from wells. The valley soil is, for the most part, underlaid with a formation of gravel, sand, and bowlders, which formation extends to a considerable depth. This is in general the water-bearing strata, and acts as a reservoir for all excess water that percolates through the upper soil. In some instances the soil is underlaid with thick layers of quicksand, and such strata also furnish an abundance of water. It is obvious that a large portion of the water found in the upper gravel stratum is due to the abundant and successive irrigations of the soil above during periods of high water, as during the past year of scant supply the level of the underground water has been lowered a number of feet. It is believed by the writer, therefore, that a bored well has an advantage over an open dug one, inasmuch as it is not dependent on the upper stratum of water alone, but draws on successive strata, which are ordinarily shut off by intermediate layers of impervious clay. It is evident, in any event, that in sinking open wells these facts should not be overlooked, and they should not only be excavated as deeply as possible in the first instance, but in a manner that will admit of further lowering.

If the theory is correct that by heavy winter irrigation we are storing our surplus water in the underlying strata of gravel, it seems a logical sequence that by means of pumping plants we should draw on this underground reservoir during periods of low water.

ECONOMY IN THE USE OF WATER.

While an increased water supply is the consummation of all our hopes, the dry season through which we have passed has taught us to better appreciate and economize the supply on hand. Perhaps never in the history of the valley has the water been so economically distributed and used as during the past year, and crops have been harvested yielding far beyond the hope of the harvesters. For instance,

Dr. A. J. Chandler, farming under the Consolidated Canal, sowed 60 acres of old alfalfa land to barley in November of 1899. Previous to plowing he irrigated the land thoroughly. The water covered the land 10.5 inches in depth and soaked slowly into the ground. After plowing, the land was double disked and seeded heavily to barley, using a press seed drill. Owing to scarcity of water only one additional light irrigation could be given on 22 acres of the tract, and in the interim, between November, 1899, and June, 1900, when the crop was harvested, the total rainfall was only 2.59 inches. The writer has no data as to the amount of water applied during the second irrigation on the 22-acre tract above mentioned, but does not think it exceeded 6 inches in depth. From this 60-acre tract 1,222 sacks of fine barley were thrashed, averaging 103 pounds per sack. A portion of the tract—17.7 acres—which received but the one irrigation before the land was plowed, yielded 400 sacks, or 22.22 sacks per acre, being as large a yield as that obtained from the land which received the second irrigation.

This record shows what can be done with a limited supply of water and a minimum rainfall. It is but fair to state, however, that the crop was greatly favored by a cool spring, but the showing made is remarkable notwithstanding.

ECONOMY IN THE USE OF STOCK WATER.

The farmers are realizing more and more that water is too precious to be wasted in the several hundred adobe holes of this valley, and many ranches have established pumping plants for stock purposes. Heretofore in the summer seasons we have wasted a large portion of our total supply of water by allowing it to seep away and evaporate in mud tanks and in the long ditches leading to them. This is not only a useless waste of water, but it is a recognized fact among stockmen that their cattle do not thrive as well on such a supply as they do on the clear, fresh water furnished from wells.

ECONOMY IN DISTRIBUTION.

Some of the canals, notably the Mesa, have been increasing the efficiency of their supply by a system of time rotation. The Mesa Canal zanjero, as a rule, divides the water among 18 laterals, but during the past summer, as the supply diminished, a system locally known as "doubling up" was instituted, whereby the total head of water in the canal was apportioned to but three or four laterals for a certain number of hours, then changed to another set of laterals, and so on until the whole number had been served. As the system pursued by this canal allows every farmer under a lateral to receive the entire head flowing in the same for varying periods of time, depending on the number of shares owned in the Mesa Canal, this plan of distribution is obviously more economical and practical than any other that could be adopted under the existing conditions.

Only with improved conditions, such as would be afforded by storage reservoirs, can water be made to reach its highest duty in Arizona. Perhaps the acme of economical use will be insured only when the consumer pays for his water according to the quantity used. This system of distribution would tend to make every user more or less of a student as to the duty of water, and there would be but little disposition to waste that which would have to be reckoned for later on in dollars and cents.

LOSS OF WATER FROM CANALS BY SEEPAGE AND EVAPORATION.

While the canals of the Salt River Valley are generally lined with an almost impervious silt deposit that renders them economical water carriers, the fact remains that a large portion of our low-water supply is wasted in the endeavor to spread a small amount over a large area through many miles of main canals and laterals. The writer has made a number of measurements during the past summer to determine the loss of water per mile in some of the large canals of the valley. Conditions must be nearly perfect as regards regular flow to determine this loss, and measurements were taken in times when the flow had been steady and uniform for a number of hours. The following table shows the results of the measurements made:

Losses by seepage and evaporation from Arizona and Consolidated canals.

Date of experiment.	Duration of experiment.	Volume received at upper end of canal section.	Volume discharged at lower end of canal section.	Volume lost in section of canal.	Length of section.	Length of wetted cross-section.	Width of water surface.	Part of total supply lost.
Arizona Canal.	*Hours.*	*Cubic feet per sec.*	*Cubic feet per sec.*	*Cubic feet per sec.*	*Miles.*	*Feet.*	*Feet.*	*Per cent.*
June 26, 1900	8	79.8	75.6	4.2	6	38	36.7	5.26
Aug. 4, 1900	6	93.25	88.75	4.5	6	38.5	37.1	4.83
Oct. 8, 1900	12	113	....	6.5	12	37.1	36	5.75
Consolidated Canal.								
May 29, 1900	6	124.6	121.1	3.5	4	43.5	42.8	2.81
June 26, 1900	8	22.8	20.8	2	4	40.2	39	8.73
Aug. 4, 1900	9	53.25	50.45	2.8	4	41.1	40	5.26

The last measurement taken of the Arizona Canal was on October 8. Since there was a lateral diversion of 378 inches between the points selected for the two measurements, I submit additional data concerning this measurement:

	Inches.
Volume of water in canal at a point near new crosscut	4,520
Volume of water in canal at a point 12 miles west of crosscut	3,882
Loss in 12 miles	638
Intermediate diversion from canal for Indian ditch	378
Direct loss from seepage and evaporation in 12 miles	260
Average loss per mile	21⅔

Conditions are more favorable in the Arizona Canal for such measurements than in any of the other valley canals, as it affords a greater number of miles with uniform cross sections, and practically free from side laterals. The above loss per mile is less than the average of previous measurements, but as the latter were made in the summer season it is not surprising. In times of scarcity a saving would be effected by a system of rotation among the large canals of the valley, but this plan might not be possible in all instances, owing to existing water-power plants that make intermediate use of the water belonging to various canals for power purposes.

EVAPORATION.

The evaporation for Arizona is high, as might be expected from a country blessed with such a high percentage of sunshine. The most complete records available to the writer are those compiled in Bulletin No. 27 of the Arizona Agricultural Experiment Station, from observations taken at the University of Arizona, near Tucson, by Edward M. Boggs, C. E.

The measurements were taken in a galvanized-iron tank, 6 feet long, 4 feet wide, and 4 feet deep, sunk in the ground, its edges flush with the surface. The water level was kept within a few inches of the top at all times, and elevation read by means of a Boyden hook gage, reading directly to one one-thousandth of a foot, and estimated to one ten-thousandth of a foot.

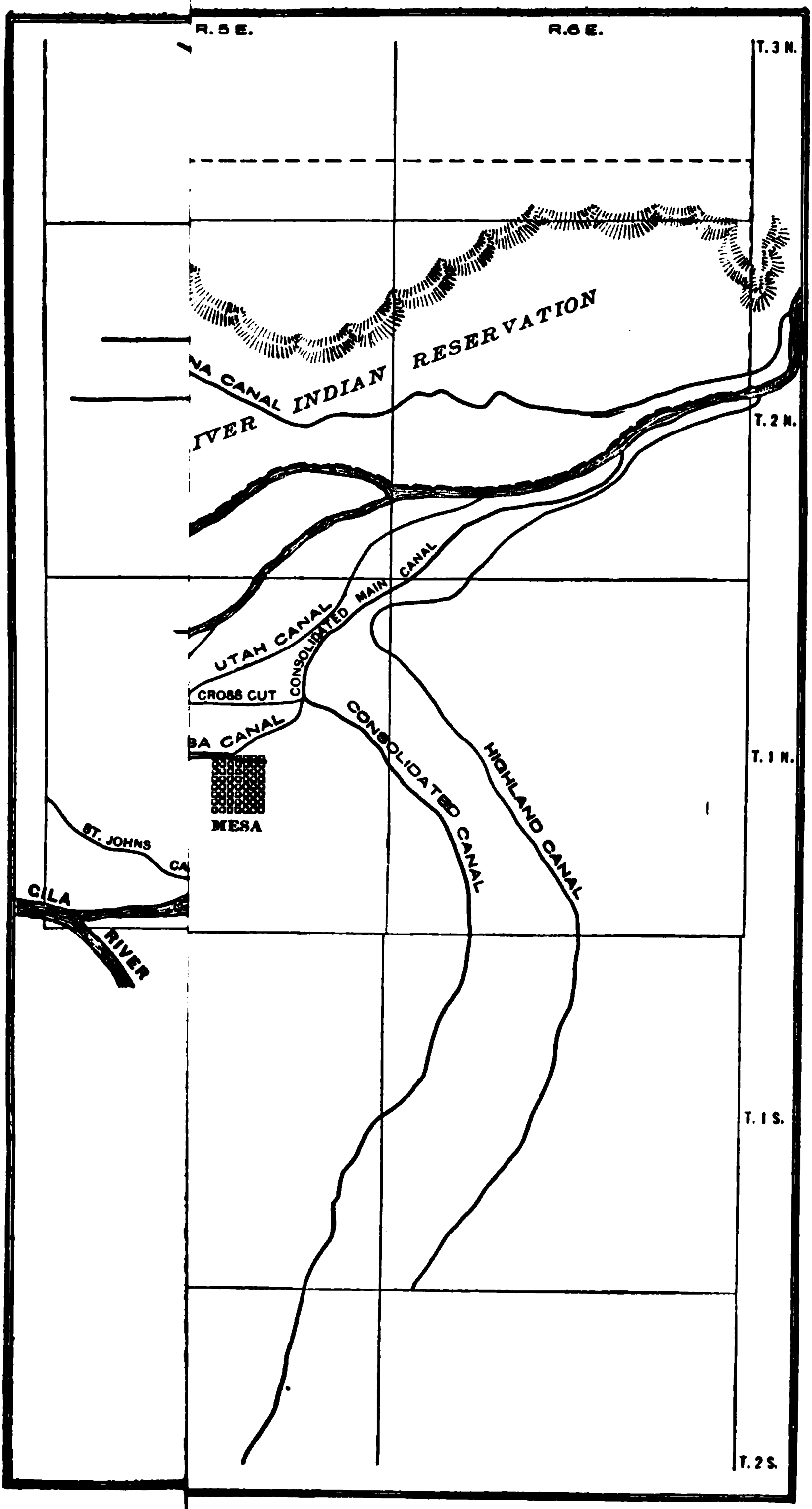
As the tank is situated the measurements of evaporation at this station probably represent the maximum for the surrounding region, and may be considerably in excess of that from the surface of a large body of water. The mean annual evaporation at this place for three years of its record is 77.5 inches. This depth is somewhat less than that commonly attributed to this region.

The following table gives the records as kept by Professor Boggs:

Records of evaporation taken at University of Arizona, near Tucson, Ariz.

Month.	1892.	1893.	1894.	Average.
	Inches.	*Inches.*	*Inches.*	*Inches.*
January	2.68	3.04	2.56	2.76
February	2.41	3.51	3.03	2.98
March	4.29	4.87	4.47	4.41
April	6.32	7.73	6.81	6.95
May	9.31	9.17	8.69	9.06
June	11.02	11.32	10.53	10.96
July	10.43	9.72	10.14	10.10
August	10.35	6.68	9.58	8.87
September	8.37	6.46	9.90	8.24
October	7.14	5.24	6.80	6.39
November	4.44	3.51	5.09	4.35
December	2.65	2.82	1.89	2.45
Total	79.41	74.07	79.49	77.52

The writer has made observations for a portion of the past year on the rate of evaporation from an open galvanized-iron tank set 2 feet



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in the ground and located in an alfalfa patch which was kept closely cropped. Measurements were taken every two weeks, and the results are smaller than those shown in the records of Professor Boggs. This may be accounted for by the presence of trees and surrounding vegetation, the former shutting off the breeze to a greater or less extent, though not in the immediate vicinity of the tank, and the latter, particularly the alfalfa, cooling the surface of the ground surrounding the tank. The summer was also cooler than usual, with the exception of the month of July. The results of the measurements are as follows:

Record of evaporation near Mesa, Ariz., 1900.

	Inches.
May 2-16	3
May 16-30	3.25
May 30-June 13	3.37
June 13-27	3.67
June 27-July 10	5.12
July 10-24	4.25
July 24-August 7	4
August 7-21	3.75
August 21-September 4	3.50
September 4-18	3
September 18-October 1	2.75
October 1-15	2.50
October 15-29	2.25
October 29-November 12	2
Total	47.41

RETURN WATER.

The amount of water that returns to the Salt River after being used for irrigation on the higher lands above is an interesting study, and one that disproves to some extent the old adage, "You cannot eat your cake and have it."

The entire low water supply of the Salt River is taken from the river channel by the time it reaches the head of the Utah Canal. Practically no water passes the Utah dam, and the river bed for several miles below is as dry as dust. After following the river channel, however, for a distance of 6 or 7 miles, water again appears, and at a distance of 12 miles below the Utah dam, where the return flow is picked up by the jointhead of the Maricopa and Salt canals (see map, fig. 16) the flow in ordinary years is found to approximate 60 cubic feet per second. This flow has naturally decreased during the past summer, owing to the scanty irrigations received by the Mesa, Utah, and Tempe lands above, and to the gradual lowering of the undergound supply.

The river bed is again dry below the dam of the Maricopa and Salt canals, but at the head of the Buckeye Canal, some 24 miles farther down the stream, is again found a volume approximating in ordinary

summers 150 cubic feet per second. This return flow, however, does not all come from the Salt River, as the head of the Buckeye Canal is below the junction of the Salt and Gila rivers, and immediately below the mouth of the Aqua Fria wash.

The river channel is again robbed of its supply at the Buckeye dam, but at the head of the new Arlington Canal, some 20 miles below the Buckeye, I am told another return flow of approximately 50 cubic feet per second is to be picked up by the new canal and utilized by the farmers west of the Hassayampa wash. Just what proportion of the water applied to the lands of the valley returns to the river is manifestly a hard question to determine.

The writer submits the following data, based on the assumption previously given, viz, that the supply of the Maricopa and Salt canals (jointhead) in normal stages of the river is largely return water from the irrigated lands above. Nearly all of such lands above the said canal are on the south side of Salt River, but to cover the supply furnished to Scottsdale and the Indian reservation, which are situated under the Arizona Canal above the said jointhead, I have added 500 inches constant flow to that allowed the south side of the river. Since there have been but seven days of excess of flood waters received by the Jointhead Canal during the past year, the conditions have been very favorable for determining the proportion of water it has received each month in comparison to the amount furnished to the irrigated lands above.

Proportion between the waters received by Jointhead Canal and the amount used for irrigation on lands above same from October 1, 1899, to October 1, 1900.

Month.	Average monthly flow in jointhead.	Average monthly flow on irrigated lands above jointhead.[1]	Water received by jointhead as compared to amount applied on irrigated lands above same.
1899.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*
October	83.40	316.9	26.3
November	52.40	231.5	22.6
December	66.40	224.6	29.5
1900.			
January	52.60	232.6	22.6
February	51.30	232.8	22.1
March	50.25	216.5	23.2
April	48.70	230	21.1
May	46.20	243.6	18.9
June	40.30	83.1	48.5
July	35.60	56.7	62.7
August	43	151.4	28.4
September	43.50	135	32.3
Average amount for year			29.8

[1] Including 12.5 cubic feet per second for Indian supply and Scottsdale.

While it is impossible to determine just what proportion of the average volume received by the Jointhead Canal is return flow, it is the belief of the writer that by far the greater portion of it is due to the irrigation of the sixty-odd thousand acres of land situated above the headgates of the canal. In average years a table prepared as above would be of little value, as during flood seasons the upper canals are frequently unable to take all the water, and it flows on down the river, giving the Jointhead and the other canals below the benefit of an additional supply. It would clearly be impossible, therefore, under such conditions, to determine even roughly what proportion of the water received by the lower canal is return water.

The investigations of Professor Forbes of the University of Arizona tend to prove the correctness of the above theory as regards seepage or return water. He has made the analysis of water taken from the river at the upper end of the valley above the irrigated lands, and upon comparing it with samples taken the same day from above the Jointhead, Buckeye, and Arlington canals, he found that the percentage of salts became greater as the distance from the upper end of the valley increased. Professor Forbes reasons, therefore, that the increase of salts found in the water at the heads of the lower canals is due to the leaching out of a portion of the alkali from the soils above the canals by means of irrigation.

FOREST RESERVES.

There has been considerable anxiety felt during the past year by the residents of this valley concerning the prospective throwing open of the forest reserves within our drainage area for grazing purposes. A commission was sent from Washington to examine these reserves and its personnel was of such a high order that the citizens of the valley feel confident that justice will be done all parties interested in their decision. The authorities in Washington have studied this great national question carefully for years, and in a report by B. E. Fernow, then Chief of the Division of Forestry of the United States Department of Agriculture, appears the following extract which is pertinent to the subject:

> The favorable influence which the forest growth exerts in preventing the washing of the soil, and retarding the torrential flow of water, and also in checking the winds and thereby reducing rapid evaporation, further in facilitating subterranean drainage and influencing climatic conditions, on account of which it is desirable to preserve certain parts of the natural forest growth and extend it elsewhere; this favorable influence is due to the dense cover of foliage mainly, and to the mechanical obstruction which the trunks and the litter of the forest floor offer. Any kind of tree growth would answer this purpose, and all the forest management necessary would be to simply abstain from interference and leave the ground to nature's kindly action.

Another very strong reason for the preservation of the forest reserves within the boundaries of our drainage area is the fact that the forests prevent, or at least check, to a great extent, the disastrous erosion

that otherwise occurs as a result of the frequent local rainstorms and cloudbursts common to our mountain regions. Such a rain falling on mountains and foothills whose forests have been destroyed by fire or otherwise, where there is little undergrowth, and the ground is bare of all grasses, is precipitated at once down the steep slopes to the river as though shed from a great roof. In its mad rush it not only brings to the river channel an enormous amount of débris such as brush, limbs, stumps, and whole trees, but creates many canyons and chasms, some of them of dizzy proportions when it is considered that their inception was perhaps due to an innocent appearing cattle trail leading to the river. The products of such erosions are deposited in the river channel to be swept down to this valley with subsequent heavy floods, together with the débris before mentioned, viz, dead limbs, stumps, trees, etc. The latter are a menace to all irrigation structures along the river, while the heavy sand and fine gravel are deposited in the heads of our canals, seriously diminishing their capacities and entailing great expense in subsequent removal.

VARIABLE WATER SUPPLY.

Water Commissioner Trott has kindly allowed the use of a chart compiled by him, showing the total combined head of water for each day of the year received by all the canals of the valley. This chart covers a period of four years, 1896 to 1899, inclusive, and contains data of much value to the citizens of Maricopa County. An inspection of the profile lines of this chart (fig. 17) will make apparent to the most casual observer the disadvantages under which we labor as a result of so variable a water supply. We are frequently compelled to use water simply for the reason that it is to be had at the time and will not be available later on when crops will be suffering for it.

Under these conditions of irregular water supply, it is not surprising that the lands of the Salt River Valley use a depth of 3.5 to 4 feet of water during the twelve months of the year and still fall far short of the production of maximum crops.

The terms "uniform flow" and "uniform heads" have been used several times in this report, but it was not intended to convey the impression that our canals should run any certain constant volume throughout the year, or that the consumer should be allowed a uniform head to run continuously in event of reservoir construction. This would be far from a proper use of water, as the flow in the canals and the frequency of rotations or "turns" to the consumer should depend solely on the requirements of the crops. It is beyond doubt, however, that the highest efficiency of water would be obtained by giving the users a good constant head during these rotations, especially for the irrigation of the staple crops by flooding.

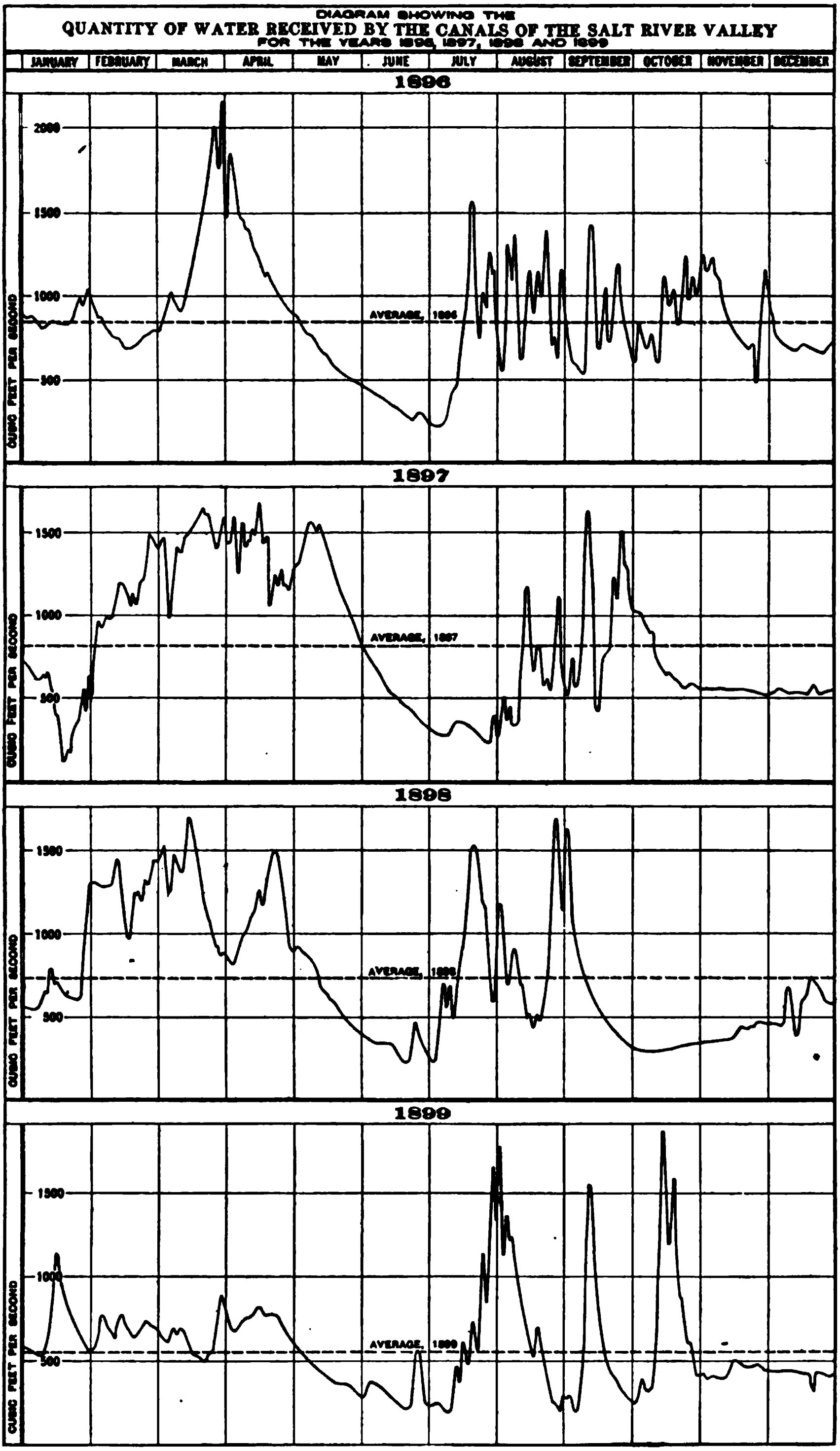

FIG. 17.—Diagram showing quantity of water received by the canals of Salt River Valley for the years 1896, 1897, 1898, and 1899.

DUTY OF WATER IN SALT RIVER VALLEY.

In a report on this subject, prepared last year, the writer endeavored to show the duty of water under the Mesa Canal. This canal was selected because the writer is especially familiar with the system and because he has access to carefully prepared daily records extending back for several years. At the same time it was believed that the conclusions reached would be applicable to a considerable extent to other parts of the Salt River Valley, where there are similar conditions.

For the season of 1900, as before stated, it was decided that the work would be extended to include the valley generally, though the results would be more general than those of the detailed investigations to be continued under the Mesa Canal. To have made a detailed study of the duty of water in the Salt River Valley for the past season would have required conditions more favorable than those which have existed, and the intention of this report for the present year is: First, to show the total quantity of water that has flowed past the gaging stations in each canal in the valley from October 1, 1899, to October 1, 1900. Second, to give the area of land farmed under each of the said canals, and the quantity of water applied to the ground during the year. Third, to submit such general data as the writer thinks of interest to the valley concerning pumping plants, available underground supply, tables showing proportion of return water, etc.

The people of the Salt River Valley need no report to convince them that they have passed through a season of unusual dryness, which has been more or less general from Mexico to the Northwest.

The writer regrets exceedingly that this report covers a dry season, as it will be more or less meager in detail as a consequence, but such data as are herewith submitted may be of some value in showing what the actual shortage has been throughout the year under the various canals, and this knowledge should be useful in any plans for guarding against such shortage in the future.

In the pages which follow a brief description of each canal in the valley is given, together with tables showing the area irrigated and the water used under each.

TEMPE CANAL SYSTEM.

The Tempe Canal was first taken from Salt River in 1870, and is owned and operated by a community of farmers and stock growers. Its main trunk is less than 2 miles in length, and has been enlarged from time to time, until its present capacity is 325 cubic feet per second. Its quota of water is divided among several branches and extensions, which in the aggregate irrigate over 30,000 acres of fine lands. One of its lateral canals, known as the Hayden Ditch, furnishes water power for milling purposes in the town of Tempe, ordi-

narily carrying 1,100 inches, or 27.5 cubic feet per second, for this purpose.

The San Francisco or Wormser Canal now receives practically all of its water from the tailrace of the milling plant referred to, although it is possible for it to maintain an independent head.

The management consists of a board of directors elected by the stockholders, and this board appoints its president, treasurer, and secretary; also a superintendent and two zanjeros. There are 109 shares in the main canal, each share representing about 100 inches during high water and its proportional part of whatever the canal is carrying at all seasons of low and medium supply. The shares have increased largely in value in the past few years, being now considered worth at least $4,000. The salaries paid the officers in direct charge are as follows:

	Per month.
Superintendent	$90
Secretary	75
Zanjero	60

Zanjeros must furnish their own conveyances.

Annual assessments on the main canal approximate $50 per share, from which are paid all salaries, legal expenses, maintenance of main canal, dam, etc. The water consumers on all lateral canals are assessed additionally for repairs and maintenance of the same.

The distribution of water is directed by the superintendent, and the zanjeros, as a rule, simply turn the proper proportion of water from the canals into each lateral, it being then taken charge of by the consumers under the laterals, who arrange their hours according to the shares or fractional parts thereof owned by each rancher.

The new board of directors, recently elected, adopted a praiseworthy resolution, abolishing the stock-water nuisance, and while it may work a temporary inconvenience and some little expense to the ranchers under the system, they will be amply rewarded by the extra amount of water received for irrigation purposes during seasons of scarcity.

The lands under the Tempe Canal are for the most part utilized for the growing of alfalfa, grain, and sorghum, and as a consequence it is one of the best sections of our valley for stock raising. The canal, being one of the oldest in the valley, has a very good water supply. I submit herewith a table showing average monthly and yearly flow from September 1, 1895, to September 1, 1899; also summary giving total number of acre-feet applied to the irrigated lands for this period. I am indebted to Water Commissioner Trott for this data.

Average monthly and yearly flow of Tempe Canal, 1895–96 to 1898–99.

Month.	Average monthly flow.			
	1895–96.	1896–97.	1897–98.	1898–99.
	Inches.	*Inches.*	*Inches.*	*Inches.*
September	5,648	7,591	8,199	5,205
October	7,372	7,026	7,433	4,368
November	5,071	7,216	3,776	4,840
December	7,150	6,698	6,362	6,491
January	7,584	4,443	7,011	6,793
February	7,555	7,094	11,496	6,788
March	10,780	11,190	10,373	6,747
April	9,575	10,558	9,297	7,382
May	6,465	9,672	6,607	5,261
June	4,168	5,944	4,624	3,951
July	6,289	4,138	6,859	5,866
August	6,870	6,382	7,611	7,146
Total	84,547	87,952	89,648	70,836
Average annual	7,044	7,330	7,470	5,911

Summary.

	1895–96.	1896–97.	1897–98.	1898–99.
Area irrigated ..... acres	30,000	30,000	30,000	30,000
Discharge of canal ..... acre-feet	128,638	132,666.9	135,200.8	106,985
Discharge per acre irrigated ..... do	4.29	4.42	4.51	3.57
Estimated loss of 20 per cent ..... do	1.07	1.11	1.13	.89
Depth of irrigation ..... feet	3.22	3.31	3.38	2.68
Rainfall ..... foot	.55	.94	.53	.58
Total depth of water received by land ..... feet	3.77	4.25	3.91	3.26

The cost per acre-foot of water under the Tempe Canal system ranges from 40 cents for lands directly under the main canal to 80 cents for those situated at the lower end of its longest extensions. There are several reasons for this wide variance in price, the chief one being that the lands under the main canal are subject to but one canal assessment, and that as they suffer but a minimum loss of water through seepage and evaporation they require a less number of shares for a given area of ground. Below is given a table showing the daily flow of the Tempe Canal from October 1, 1899, to October 1, 1900. The summary shows the total depth of irrigation in feet, rainfall, etc. It will be noted that the writer has estimated a loss from seepage, evaporation, and waste of but 20 per cent during the past year, which is smaller than the percentage usually deducted. One reason for this has been previously stated, viz, that the past year of limited supply has forced a greater or less degree of economy in the use of water which has hitherto been deemed unnecessary. Again, the improved system of distribution which has been established during the past year has effected a great saving of water to the canals of the valley.

1900.

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	August.	September.
							Acre-feet.	Acre-feet.
1						[illegible]	40.4910	143.1540
2						[illegible]	23.7600	142.1145
3						[illegible]	49.1040	129.8385
4						[illegible]	71.5770	133.7985
5						[illegible]	76.9230	129.6900
6						[illegible]	123.6510	129.6900
7						[illegible]	183.4965	118.8000
8						[illegible]	173.2995	110.9295
9						[illegible]	205.5240	101.4750
10						[illegible]	100.8810	108.0585
11						[illegible]	115.8300	179.9820
12						[illegible]	109.5930	194.8815
13						[illegible]	90.2880	170.0620
14						[illegible]	85.8330	153.5490
15						[illegible]	72.4680	159.0930
16						[illegible]	74.2500	158.0040
17						[illegible]	74.2500	142.1145
18						[illegible]	284.1300	146.2330
19						[illegible]	347.7375	138.6990
20						[illegible]	374.8140	121.2750
21						[illegible]	287.2485	123.7500
22						[illegible]	238.5900	130.4325
23						[illegible]	222.3540	185.8775
24						[illegible]	224.7300	276.6060
25						[illegible]	212.6520	198.6435
26						[illegible]	201.9600	193.8915
27						[illegible]	175.0815	191.4660
28						[illegible]	142.5600	185.7735
29						[illegible]	121.2750	184.6350
						[illegible]	118.1565	184.7835
						[illegible]	129.7395	....
	[illegible]	[illegible]	8,189.8740	8,418.4155	2,630.9745	1,430.5500	4,752.2475	4,617.3205

Summary.—Duty of water under Tempe Canal for year ended September 30, 1900.

Area irrigated	acres	30,000
Discharge of canal	acre-feet	86,431.78
Discharge per acre irrigated	do	2.88
Estimated loss from waste, seepage, and evaporation, 20 per cent	acre-feet	.58
Depth of irrigation	feet	2.30
Rainfall	foot	.27
Total depth of water received by land	feet	2.57
Area served by a continuous flow of 1 cubic foot per second	acres	251
Area served by a continuous flow of 1 miner's inch	do	6.30

UTAH CANAL SYSTEM.

The Utah Canal and extension is owned by a cooperative association of farmers, and the main trunk was first used in 1877. The original Utah Canal, which was taken out by a Mormon colony, was divided into but 7 shares, and was only a few miles in length, irrigating the bottom lands of what is now known as the Lehi settlement. Seventeen shares were subsequently added, then another 8, giving a total of 32, and on January 8, 1884, each of these shares was divided into four parts, giving the present total of 128.

The main canal was extended and enlarged in 1888 by settlers on the higher mesa lands southwest of the Lehi settlement, and their extension now runs 78 of the shares. There are also a number of what are known as high-water rights. This mixing up of old and new shares has caused more or less dissension, the owners of old shares protesting against any division of the water with the high-water contingent.

The annual assessment on an original share varies according to the number of floods throughout the year, each one of which invariably necessitates repairs to dam or head of canal. They approximate on the main canal $25 per share or 65.5 cents per acre, each share being sufficient to irrigate a 40-acre tract and having a present cash value of approximately $500.

The Utah Canal and its extension are each controlled by a board of three directors, who are elected annually by the stockholders. The active management is the same in each instance, consisting of a president, a secretary, and one zanjero. Water is given to all stockholders when the river is high, and rotated during low water.

The lands under this system are for the most part utilized for diversified farming and stock raising. For the four years prior to 1900 this system supplied its underlying lands with nearly 4 acre-feet of water per acre per annum.

There is a small settlement of Maricopa Indians under the Utah

Canal proper, and a recent court decision awards them one-tenth of the first water received by the canal up to the time when it carries 3,000 inches (75 cubic feet per second). This little stream of water makes them independent and contented, and during a nine years residence within a few miles of their settlement the writer has never observed any beggary or thieving on their part.

The following table shows the daily flow in Utah Canal for the year ended September 30, 1900, and also gives depth of water applied to land, rainfall, etc.

Flow of water in Utah Canal October 1, 1899, to September 30, 1900.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	38.8080	65.5875	76.8735	67.0230	84.1500	64.4985	63.7560	166.8150	33.0165	15.6420	25.5420	37.6695
2	37.1250	76.4280	92.3175	68.0625	82.6165	65.1420	61.8750	197.7525	33.7095	14.3550	22.0275	36.6300
3	35.4420	62.8155	84.6945	76.9230	87.9615	68.7555	56.8755	132.9570	38.4120	13.8600	22.9680	32.9670
4	38.8080	53.4105	77.3685	77.3685	77.0220	65.1420	59.9940	134.6400	35.4420	14.5530	23.9085	30.4425
5	49.5000	54.6975	76.8735	75.8835	96.7230	64.5480	72.4185	128.1555	37.0260	14.0085	22.3740	34.6995
6	52.0740	59.1030	78.4080	75.8835	96.1785	64.6965	92.8620	128.7990	32.9175	13.5135	24.2550	38.2635
7	55.5885	61.8750	79.4475	72.4185	91.7235	65 5875	84.1500	115.6320	31.5315	13.8105	44.6490	34.6995
8	50.3415	70.4385	76.0815	75.8835	90.0900	64 6965	87.8625	127.5120	31.2345	12.8700	38.5605	35.0460
9	53.8065	73.9035	76.2795	76.3785	93.4065	63.7560	91.7730	112.6125	28.4625	14.8005	31.5315	31.2345
10	55.1430	66.6270	76.3785	74.3985	96.7230	63 7065	90.0900	115.8300	27.7695	15.3450	25.7895	32.9175
11	55.5390	65.5875	77.3685	73.9035	94.0500	61.8750	88.9515	105.7320	25.8390	14.5035	25.7895	47.5695
12	353.4795	67.0230	79.9920	76.8735	92.8620	62.3205	81.5760	110.3355	28.5120	14.2560	25.5420	59.5980
13	399.6135	67.9635	83.1105	77.8635	90.0405	60.1425	78.9525	81.0810	36.1845	12.5730	25.5420	54.0045
14	260.6175	68.4585	83.1105	81.9720	93.4065	65.1420	76.4280	94.4955	28.6110	12.3255	25.1955	43.8570
15	396.3960	73.4085	81.5760	61.6770	89.0010	68.4585	72.9135	80.4870	23.3145	11.8710	23.3145	39.9465
16	377.2890	70.0425	82.0710	84.8480	73.4085	65.5875	71.9235	71.9235	24.2550	13.4145	22.6710	39.5505
17	296.6535	76.8240	79.9920	87.4170	71.4285	66.0330	72.9135	55.9845	26.1360	12.8255	23.2650	38.4615
18	140.6790	83.6550	74.3985	75.3685	69.4485	66.5280	74.3985	63.0135	24.8490	12.0285	85.5360	32.2740
19	135.3825	96.2280	73.4085	78.7550	70.9335	68.7060	71.0325	58.8060	26.4330	12.5730	233.1945	29.8485
20	138.0060	90.6345	76.3785	79.4475	75.8835	67.4685	65.1420	49.9455	25.7895	15.0975	287.6940	27.8190
21	106.3260	88.4565	83.7045	84.6945	78.4080	69.5970	65.5875	42.2235	25.1955	43.4610	122.3640	30.8385
22	96.1785	84.6945	82.6155	85.2390	80.5365	72.9135	65.1420	56.0835	20.3940	33.0165	79.4475	32.2245
23	105.3855	85.7340	82.6155	86.8230	77.8635	85.8330	67.6170	65.7360	15.9390	31.2345	73.9035	81.1305
24	96.8715	90.6345	90.0900	87.8625	78.4080	84.1995	70.4385	59.5980	17.8200	36.1845	62.1720	84.6945
25	92.2680	90.6840	83.6550	90.0900	78.4080	80.5365	75.8835	52.1730	19.9980	33.9570	45.8370	68.4585
26	93.9015	91.1790	93.4065	84.6945	74.8935	77.3685	75.3885	47.9655	15.3450	33.2640	44.8965	57.9645
27	90.6345	82.8630	70.4385	80.4870	72.4185	74.8935	76.8735	43.0650	13.8600	25.5420	36.9270	42.1740
28	86.8725	77.8635	78.0615	76.4280	69.9435	71.9235	92.3670	40.0455	14.1075	19.0575	35.0460	44.5995
29	82.0710	73.4085	81.5760	77.3685	....	78.9035	113.8500	49.5990	17.0775	20.2455	35.0460	39.9465
30	73.4085	78.4080	70.9335	77.9130	....	73.4085	113.1570	43.0155	15.5925	20.4930	33.2640	35.4420
31	68.4585	....	67.4685	79.9920	....	68 7555	....	32.9670	....	17.0775	37.3230	....
Total	4,012.6680	2,248.6365	2,470.6935	2,374.9605	2,327.9355	2,136.1230	2,382.1925	2,664.9810	774.7740	587.1690	1,665.5760	1,274.9715

Summary.—Duty of water under Utah Canal for year ended September 30, 1900.

Area irrigated	acres	10,000
Discharge of canal	acre feet	24,870.69
Discharge per acre irrigated	do	2.49
Estimated loss from waste, seepage, and evaporation, 20 per cent	acre feet	.50
Depth of irrigation	feet	1.99
Rainfall	foot	.27
Total depth of water received by land	feet	2.26
Area served by a continuous flow of 1 cubic foot per second	acres	251
Area served by a continuous flow of 1 miner's inch	do	6.30

MESA CANAL SYSTEM.

This system will be but briefly discussed, as it has been ouite fully described in a previous report by the writer.[1]

The original Mesa Canal was constructed in the year 1878 by a band of Mormon pioneers. The head of the canal for 2 miles was an open cut along the edge of a sand mesa adjoining the river channel. This unstable head was naturally a most expensive one to maintain, and the early settlers spent a considerable portion of their time in "bucking sand out of the head," and rebuilding a brush and rock dam. This undesirable condition of affairs continued until 1891, at which time the Consolidated Canal Company, by a certain contract with the stockholders of the Mesa Canal, took possession of the first 8 miles of the latter and commenced the construction of a stable and permanent canal.

The shareholders of the Mesa Canal now receive their water at the division gates of the Consolidated Canal Company, and are thus relieved of the burden of maintaining unstable headworks, besides being assured of their quota of water at all seasons.

The management of the Mesa system consists of a board of five directors, elected annually by the stockholders. This board selects its president, and also appoints a secretary and one zanjero. Annual assessments on each of the 400 shares of the stock of the company average $16. The cost of water, as learned through investigations of 1899, approximated 50 cents per acre-foot for that year.

This system covers remarkably fine, productive lands. A tract of 6,000 acres which was selected for last year's investigations yielded gross returns in eight months amounting to $77,203.39. This gives a gross income per acre of $12.87 for the first eight months of 1899, and the lands would average a proportional return for the remaining four months, since they produce to a greater or less extent throughout the entire year.

Below are given tables showing daily flow in Mesa Canal from October 1, 1899, to October 1, 1900, and the duty of water under the canal.

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

Flow of water in Consolidated Canal (Mesa water) October 1, 1899, to September 30, 1900.

Day.	October.	November	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	37.1250	72.6165	86.2290	68.7555	89.7930	62.9145	58.9050	287.2980	49.9950	16.8300	28.0865	35.5905
2	39.1050	105.6825	107.4150	71.9730	82.4670	66.1815	61.0830	252.0045	41.6790	18.1665	47.0250	43.5105
3	39.1050	107.3655	85.0410	80.2890	85.0905	65.4390	62.1720	171.7650	32.3730	19.6515	35.7390	37.8675
4	45.0450	102.5640	76.7745	75.5370	85.5855	64.3500	64.3500	169.7850	31.6800	21.4830	36.1350	40.4415
5	62.0730	53.3610	77.0220	69.6960	80.6355	66.1815	74.1510	153.7470	30.9870	16.8300	32.5710	42.3720
6	52.0245	62.0730	73.2105	73.2105	76.5270	65.4390	96.2280	156.6180	34.9965	20.8395	56.2320	41.2830
7	55.5390	68.6070	72.0225	76.7745	83.2590	64.3500	81.8730	149.3910	36.9270	20.0970	71.0825	37.3230
8	54.4500	65.7360	74.3985	80.3385	88.4070	64.3500	90.1890	154.4400	32.4720	15.9390	66.9240	42.5700
9	55.5390	63.1620	80.4375	77.0220	88.4565	63.2610	94.9410	141.2730	27.3240	16.2360	46.1340	44.5500
10	52.2720	56.6280	81.5265	73.1610	85.4865	64.6470	91.3770	122.5620	22.4730	18.1665	43.3125	35.9865
11	53.3610	65.3400	79.1505	74.3490	79.2000	61.0830	88.9515	107.1180	22.4235	18.0180	37.1250	48.8070
12	346.5000	68.6070	77.7645	85.3380	78.5070	62.1720	78.5070	106.2270	23.2155	19.5090	27.3735	62.0235
13	346.9950	64.2510	75.5865	83.8530	80.7840	61.9740	77.4180	86.6250	20.8890	17.7210	32.7690	53.9550
14	346.5000	67.5180	76.9725	83.9025	84.2490	65.4390	73.0620	94.5450	28.3635	13.7115	26.5320	50.5890
15	346.5000	80.2890	79.1010	117.3150	77.5170	65.4390	74.1510	102.5145	25.5420	17.8695	29.1060	43.2630
16	353.9250	80.6850	82.7145	146.7180	75.6855	65.4390	68.7060	79.9920	25.4430	15.3450	23.8590	32.3730
17	262.6965	87.8130	81.5265	93.4560	73.8045	64.3500	71.9730	87.7140	26.3340	15.6420	26.5320	39.9465
18	181.6650	102.0690	67.5180	94.5450	75.9825	64.3500	70.8840	65.9340	29.6010	16.2360	152.7570	31.2840
19	176.3190	97.3170	73.1610	80.3385	74.8935	67.6170	68.7060	57.1725	18.6120	21.2850	375.4575	27.8190
20	139.6890	90.1890	77.9130	75.5865	75.9825	68.7060	65.4390	45.2925	16.2360	22.7700	227.6010	30.4425
21	116.4240	87.8130	92.5650	85.0410	78.5070	70.8840	68.7060	55.9845	11.4345	38.8080	154.3410	24.2550
22	119.0970	85.4370	86.2290	87.4170	81.9720	78.5070	68.7060	69.0525	17.2755	29.8980	118.7010	26.2845
23	98.4060	87.8130	81.4770	86.2290	80.5860	86.8230	68.7060	59.7960	17.2260	36.5805	70.5870	30.7395
24	97.1190	99.6930	94.5450	88.6050	77.3190	75.2895	71.9730	45.7875	14.2065	28.1160	54.4500	146.6190
25	95.8320	94.9410	60.9345	81.5265	76.3290	78.5070	76.3290	41.3325	22.6710	23.6115	47.2230	73.1115
26	98.4060	94.9410	85.5855	75.8340	74.1510	77.4180	76.3290	43.5600	15.2460	29.8980	40.7880	77.8635
27	94.6440	90.1890	74.3985	73.0620	73.1610	78.5070	79.6950	35.3430	19.9485	25.5915	44.0055	50.1930
28	85.0410	90.1890	73.4085	72.9630	69.4485	75.2400	87.1200	29.2050	17.2755	19.1070	42.8670	43.4115
29	74.3490	83.0610	69.8445	83.6550	....	73.0620	116.0280	36.5805	21.7305	34.0065	37.7190	30.7890
30	65.3400	92.5650	64.3995	86.0310	....	68.7060	131.8680	38.1150	18.9090	27.9180	33.0165	38.2635
31	66.4290	....	68.7555	89.5950	....	64.3500	....	37.5210	....	26.0865	39.7485	....
Total	4,057.5150	2,468.5155	2,437.6275	2,592.1170	2,233.0895	2,120.9760	2,358.5265	3,084.2955	753.4890	681.9615	2,103.7500	1,363.5270

Summary.—Duty of water under Mesa Canal for year ended September 30, 1900.

Area irrigated .... acres..	13,000
Discharge of canal .... acre feet..	26,287.09
Discharge per acre irrigated .... do....	2.02
Estimated loss from waste, seepage, and evaporation, 20 per cent........ acre feet..	.40
Depth of irrigation .... feet..	1.62
Rainfall .... foot..	.27
Total depth of water received by land .... feet..	1.89
Area served by a continuous flow of 1 cubic foot per second .... acres..	358
Area served by a continuous flow of 1 miner's inch .. do ...	8.95

The following tables show the duty of water on the 6,000 acres, which were discussed in the report of last year on the Mesa Canal.

Flow past the register in the Mesa Canal, October 1, 1899, to September 30, 1900.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	22.8762	35.7291	66.0649	34.3123	43.0157	36.8647	22.4584	142.0905	24.4256	8.8446	15.3698	23.3520
2	22.1478	57.8297	52.6057	38.4637	47.1222	32.2747	21.1470	86.4622	21.0951	10.0701	18.4487	21.9776
3	23.3591	21.8906	46.0629	34.0089	43.3869	32.5251	20.3514	86.8108	19.2123	10.3049	17.9034	27.1280
4	37.7330	21.8568	40.6451	32.9059	36.5708	33.6563	25.2813	79.5633	18.0116	8.1323	17.3091	22.2642
5	36.0290	31.2545	37.5406	35.6688	33.0588	34.1452	45.4807	73.6429	19.3719	8.4650	29.7913	24.1308
6	37.4744	36.0945	38.3332	36.7200	40.5510	31.7774	35.0293	71.6066	21.1442	11.0907	49.9469	24.5692
7	39.3844	39.9802	39.7961	39.5207	41.2128	30.9355	43.0916	76.9466	19.2967	10.8192	37.4815	26.0011
8	38.3753	30.0160	39.6570	36.8563	40.6195	29.6297	45.0112	74.4691	17.1951	8.9712	33.5128	26.2175
9	31.4162	26.6898	40.0743	34.9014	40.8376	31.2940	42.3005	61.0437	14.2542	11.7216	24.0310	23.1092
10	65.7896	32.3884	41.5934	35.4214	42.8627	28.9383	46.7215	59.4134	14.7766	12.2151	21.9482	38.9921
11	246.4987	33.5141	39.9324	37.6377	44.2902	24.8770	45.4513	47.1178	18.7044	10.2690	20.0631	44.1653
12	234.0275	34.9014	37.9271	39.2593	45.7576	24.7488	42.7176	42.7165	17.4493	9.7833	21.4011	34.9366
13	213.1464	35.7995	38.0682	39.6570	48.5978	26.7640	40.9034	41.8942	17.7532	9.7748	22.8263	32.1861
14	211.9829	47.5748	38.0438	72.6828	43.8815	29.1745	38.5862	45.5188	19.6111	9.0650	19.5014	28.5053
15	225.4885	33.1646	41.1846	88.8358	42.8331	30.5689	38.8532	40.5761	16.0290	9.1118	20.1140	29.3089
16	184.8203	37.5969	39.8045	46.9128	43.9969	28.9155	38.7281	40.6759	15.1928	8.3442	19.5379	27.4238
17	115.7540	51.0233	32.0357	50.1296	42.7346	27.5410	39.3900	35.4158	13.8339	6.9740	60.1513	23.6234
18	119.9069	43.2910	35.6139	43.2364	42.9960	27.4554	39.9380	34.0259	10.5775	5.6560	175.7064	23.8358
19	62.2887	33.8534	45.3698	34.4067	42.5787	25.5158	38.3248	29.2824	8.9052	6.0715	163.3463	18.6512
20	63.7221	42.0107	41.6274	40.8089	45.7550	28.3320	39.1202	27.3350	9.4516	27.7875	86.7869	14.7346
21	68.1800	40.2022	40.9543	43.1380	48.8596	30.4882	38.8392	33.6293	10.4790	15.9626	66.2323	20.4923
22	48.4084	41.8942	42.0559	43.2800	46.1806	34.8438	37.5154	27.4443	14.4916	23.3986	52.2938	17.6773
23	44.4353	46.9754	47.6957	45.1954	45.0143	29.7491	38.3108	25.1186	12.9472	20.0621	38.5094	52.5021
24	41.5876	45.1503	47.2727	48.2054	44.1482	36.0759	40.6251	24.7912	9.8945	17.4608	33.0338	50.4767
25	39.9296	45.1700	51.9188	40.0687	43.8534	34.6540	42.4479	26.0984	9.5387	18.2590	27.0942	46.1876
26	39.6570	42.3089	38.8616	35.4186	43.1605	35.6716	41.1708	21.9762	10.8263	18.4389	22.7275	38.9740
27	38.8392	46.0640	36.0295	35.5564	39.5685	30.9829	42.3566	25.0679	10.2964	14.8696	21.6440	40.3792
28	37.5070	43.8617	27.4244	46.1977	36.8955	28.9552	55.9533	25.7524	9.8579	15.1605	24.5972	36.2084
29	33.6392	48.4331	24.9992	47.6564		28.5940	57.4374	29.1800	10.8236	14.8528	23.5982	31.7674
30	32.6328	54.1446	27.4698	46.9746		25.5751	122.3729	23.6232	10.1391	14.9301	30.1258	29.7706
31	30.1497		35.5689	50.9738		25.8238		26.1825		14.5184	31.1181	
Total	2,487.1868	1,180.6637	1,252.1713	1,334.5094	1,200.3420	936.7974	1,265.9148	1,485.4770	445.5876	391.3847	1,245.6717	899.5478

FIG. 1.—DREDGE IN ARIZONA CANAL.

FIG. 2.—WHEAT IRRIGATION BY FURROWS.

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Summary.—Duty of water under Mesa Canal for year ended September 30, 1900.

Area irrigated	acres	6,000
Discharge of canal	acre-feet	14,106.49
Discharge per acre irrigated	do	2.35
Estimated loss from waste, seepage, and evaporation, 20 per cent	acre-feet	.47
Depth of irrigation	feet	1.88
Rainfall	foot	.28
Total depth of water received by land	feet	2.16
Area served by a continuous flow of 1 cubic foot per second	acres	308
Area served by a continuous flow of 1 miner's inch	do	7.70

ARIZONA CANAL SYSTEM.

The Arizona Canal, which is operated by a corporation now known as the Arizona Water Company, controls the water delivery on the north side of Salt River. Since this system embraces over 100 miles of main canals and a great number of laterals, its importance to the Salt River Valley can be easily imagined. The material prosperity of the citizens on that side of the river is largely dependent on its proper management, especially in the way of a careful maintenance of the system. During the past two years this company has expended a large amount of money in enlarging its main canal by means of two dredges (Pl. VIII, fig. 1), the work being now nearly completed. The purpose of this enlargement was to enable the company to appropriate a larger volume of water during flood periods, and in order to further insure their consumers this additional water supply the crest of the dam was raised 2.5 feet in height. By this work the north side canals will have an increased supply of at least 300 cubic feet per second during seasons of high water.

The active management of the system is intrusted to a general manager, who acts according to instructions received from a local advisory board, headed by a resident vice-president. This board is in turn directed to a greater or less degree by the president and executive committee of the board of directors, all of the latter residing in the East.

The manager is assisted by a general superintendent, who has direct charge of all the canals controlled by the Arizona Water Company, as regards water division, maintenance of canals and laterals, repairs on dam, service gates, checks, drops, etc. The superintendent has a number of zanjeros acting under his direction, there being two on each canal—the Maricopa, Salt, and Grand—and four on the Arizona Canal proper. The superintendent receives a report from the water commissioner each morning giving the amount of water his main canal (the Arizona) is entitled to receive, and the amount of return or seep-

age water in the joint head of the Maricopa and Salt canals. He thus knows the total quantity to be divided between the lands under the north side canals and instructs the zanjeros as to its daily distribution. In the summer season when the water is low these canals pursue a system of rotation, the Maricopa and Arizona taking all of the north side water for four days, after which it is turned over to the Grand and Salt canals for a similar period. The zanjeros on the Maricopa, Grand, and Salt canals simply deliver the water to the consumers at the service gates, not following it down the laterals as is the custom of the zanjeros on the Arizona Canal proper. They are all guided in the division of water by weirs and gage stakes set in the laterals near service gates by the company engineer. There are 24 laterals leading from the main Arizona Canal varying in length from 3 to 14 miles, and the supervision of these laterals is divided between the four zanjeros before mentioned, it being their duty to follow the water down each lateral and distribute it to the numerous water consumers. This necessitates a good deal of traveling on their part—from 20 to 40 miles per day—for which service they are allowed $80 per month, out of which must be paid their board and horse feed. They are also obliged to furnish their own conveyances. A private telephone system of some 70 miles enables the manager and superintendent to keep in touch with every important point on the system at all times, and many of the larger ranches have long-distance telephones installed in their headquarters, so that they are also in touch with the canal office. Without a comprehensive system of telephones it would be almost impossible to handle the water distribution of so many canals, particularly during heavy floods. The canal system is at times endangered almost as much by desert storm waters as from river freshets, as a cloudburst or heavy rain in the foothills may cause intercepted arroyos and dry washes to suddenly become raging torrents, which, though usually short lived, are nevertheless exceedingly dangerous to the canal banks while they last.

The Arizona Canal was originally designed to irrigate 96,000 acres of land, there being 1,200 water rights, each attached to an 80-acre tract. The cost of water rights is $15 per acre, and the annual assessment is $1.25 per acre, water being sold to holders of water rights only.

The duty of water is taken at 66.5 inches per quarter section, which amount is presumed to flow constantly during high water, but at times of short supply a system of rotation is adopted whereby the farmer is supposed to receive the same volume of water, but for a less number of hours.

The water rights of the Grand, Salt, and Maricopa canals are worth $10 per acre. The ownership of these canals is divided into shares entitling their owners to 80 inches (2 cubic feet per second) for each share owned, and, as is the common custom, the consumers are entitled to the maximum flow only when there is an abundance in the

river, the water at other times being prorated. The price of water which is sold only to water-right owners under these three canals is $1.50 per inch during the winter season, September 15 to May 15, and 75 cents per inch for the remainder of the year.

Tables are given below showing the combined flow of the Arizona Canal and the jointhead of the Maricopa and Salt canals for the year ended September 30, 1900; and also the total supply in Salt River for the same period, including the 12.5 cubic feet per second (500 inches) allowed to the Indians of the reservation on the north side under the Arizona Canal.

Combined flow of water in Arizona, Maricopa, and Salt (jointhead) canals October 1, 1899, to September 30, 1900.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	308.9790	412.8300	442.8270	443.4705	444.1635	415.3545	382.8330	920.8485	281.0115	174.9830	180.9720	249.6285
2	307.5980	434.3130	409.2660	444.6090	446.2425	410.7510	367.1415	1,116.6210	278.7345	170.9730	207.6030	257.9940
3	306.2070	407.6820	432.0360	437.7285	451.0935	395.7030	365.2605	1,005.7410	261.3600	173.9430	204.7815	226.7100
4	351.9450	405.1080	444.4110	444.5595	456.4890	426.0960	366.2505	833.9760	256.8060	155.8755	208.7910	243.8865
5	406.0980	446.9355	452.2815	452.8310	448.9155	397.1880	419.4630	719.8290	266.2110	176.9130	199.7325	240.5700
6	354.0735	434.3130	458.5185	445.5990	447.3315	399.6630	504.1575	681.0705	268.8345	164.9835	290.9115	240.5700
7	353.4795	437.4810	457.0335	455.0535	446.7870	396.6930	495.0000	625.7295	266.3100	151.5690	324.0270	224.8785
8	350.7075	413.6220	452.2815	442.4310	446.7375	395.2080	498.9105	675.2295	259.0830	142.4610	244.5795	224.3835
9	359.4690	433.6695	458.0235	445.9950	462.5280	407.3355	466.6365	601.9695	248.7375	144.6390	252.7470	217.9485
10	348.6285	440.7975	455.6475	462.0330	452.6775	380.8530	476.1900	574.9425	238.2930	146.0745	223.9875	224.1855
11	328.7790	409.2165	457.8255	462.2310	449.9550	365.7555	466.5375	521.5320	241.7085	139.2435	224.0370	398.5740
12	1,958.3685	410.7510	454.6575	433.2735	451.3410	365.7555	447.5295	485.2980	234.5805	122.2155	205.6725	361.2510
13	2,073.7035	399.1680	462.6765	455.0535	431.7885	333.3805	436.6890	462.7755	234.4815	122.7600	201.4155	273.7845
14	1,423.5210	396.1980	456.2415	445.1535	430.1550	371.9430	412.9290	465.5475	246.1140	123.2550	196.2180	247.9455
15	1,585.6335	429.1650	429.8580	438.8670	446.7870	387.7830	432.3825	435.6990	231.3135	126.5220	204.5835	244.8270
16	1,546.5285	447.5790	428.3235	446.8365	447.3810	386.7930	424.6605	426.3930	236.0655	130.2840	187.1100	235.5210
17	1,400.0085	502.1775	424.7100	460.9935	459.8055	393.2280	420.0570	396.0000	230.1255	129.3435	193.1490	237.4020
18	1,106.9685	579.0510	455.4495	455.9445	447.3815	386.7930	385.3080	359.4195	226.9080	129.4920	558.7560	226.4130
19	740.3220	530.9370	493.0250	480.1500	432.2340	401.1480	400.1580	330.9570	228.3930	128.4030	1,174.2885	224.3835
20	684.0900	478.5660	668.1510	488.2680	446.2425	401.1975	381.8430	315.6615	227.2050	144.0450	1,153.7460	218.0475
21	639.4410	473.5665	286.6050	467.2800	443.1735	425.5515	363.3795	324.0765	209.5335	274.3290	749.0835	221.4630
22	593.7030	470.3490	271.0125	464.1120	444.8070	485.6445	373.4280	365.3595	219.1365	197.0595	526.0365	237.4020
23	583.3080	485.7435	282.0510	459.4095	437.0355	492.7725	387.2880	352.1430	204.4845	246.8565	355.2120	217.5525
24	556.9245	479.2590	266.4090	456.2415	427.6305	456.9840	414.4635	322.6905	198.7425	211.9095	275.3190	546.3315
25	453.0735	476.0415	453.9150	446.3910	426.0960	458.4195	424.2150	328.3830	182.5560	188.5950	286.1595	411.1965
26	464.9535	453.8655	434.9070	459.9540	421.6905	447.5295	421.1460	308.9790	175.2300	183.9915	255.2220	341.1540
27	431.1935	478.5660	452.4795	466.9335	416.8890	439.2135	414.0180	297.0990	177.8040	186.5160	250.0740	306.9990
28	397.9800	484.1100	433.3230	475.9425	404.6130	414.4635	481.8825	301.5540	174.1410	192.0600	243.2430	274.9230
29	454.8555	484.8525	422.8290	464.7060	....	404.2170	624.2940	292.4460	173.3490	191.1195	241.2135	251.7570
30	423.5715	445.7475	433.5705	458.2215	....	392.7330	683.0010	292.4460	177.3090	192.1590	236.7585	269.7255
31	425.1060	....	452.5290	453.4200	....	383.8230	....	282.3480	....	178.1510	276.7545	....
Total	21,719.2130	13,581.6615	18,382.8745	14,113.1925	12,367.9215	12,639.9735	13,137.0525	15,422.7645	6,854.5620	5,135.6745	10,332.1845	8,097.4080

Summary.—Duty of water under Arizona, Maricopa, and Salt (jointhead) canals for year ended September 30, 1900.

Area irrigated ....acres	**60,000**
Discharge of canals ....acre-feet	**146,784.39**
Discharge per acre irrigated ....do	**2.45**
Estimated loss from waste, seepage, and evaporation, 20 per cent ....acre-feet	**.49**
Depth of irrigation ....feet	**1.96**
Rainfall ....foot	**.37**
Total depth of water received by land ....feet	**2.33**
Area served by a continuous flow of 1 cubic foot per second ....acres	**297**
Area served by a continuous flow of 1 miner's inch..do	**7.40**

Total flow in Salt River, October 1, 1899, to September 30, 1900.

Day.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	574.5465	834.2730	876.5460	843.1830	895.1085	800.0190	765.1710	1,721.2635	532.9170	243.0450	273.0915	466.0425
2	569.8490	880.0110	879.5655	862.5375	889.2675	807.0975	745.3215	1,980.1980	516.4830	237.6405	300.4155	480.2490
3	562.1715	870.2595	877.5360	875.5065	882.0455	800.5635	737.6985	1,727.8470	491.2380	242.3520	312.5925	427.3830
4	649.9845	828.5310	874.2690	883.3275	901.8405	824.0265	749.8755	1,533.6585	473.4180	227.5515	340.4115	448.5690
5	764.8245	826.5015	887.9310	872.0910	887.6340	799.6725	845.0145	1,348.6770	474.3090	234.4815	331.6008	447.3315
6	668.1510	824.0265	891.8910	889.9110	884.0205	793.2375	985.2975	1,288.8315	471.6360	224.5815	495.0495	449.8065
7	695.9700	827.6400	891.4455	832.0455	886.5945	786.7035	950.1030	1,184.0895	464.4585	213.1965	623.2050	415.7010
8	679.2885	810.5625	873.6255	869.1705	915.6015	784.5750	964.3095	1,262.0025	451.4895	202.4550	523.3635	412.9290
9	706.9095	838.4310	887.3370	876.7440	946.5390	798.8805	936.4905	1,143.2520	430.2540	205.3755	535.9365	395.2080
10	685.7235	834.3225	891.4455	879.6150	928.6200	772.8930	940.5000	1,107.4635	402.3855	207.0585	393.9705	401.1480
11	674.9325	808.6815	892.2375	888.3765	915.2550	749.3310	914.8590	1,024.0560	400.9500	199.9800	402.7815	674.9325
12	3,351.9915	812.6910	891.5940	876.9420	910.5030	747.1530	878.4270	995.8905	391.5450	180.5760	368.1810	677.7540
13	3,751.9020	796.6530	896.5935	916.1955	878.5260	730.1745	862.3890	918.8190	386.4960	175.5765	350.0145	551.8260
14	2,382.9795	800.7120	890.6535	914.1660	886.6935	760.9140	834.0750	920.6505	396.0990	173.1510	333.7785	495.9405
15	3,152.1105	860.0625	864.8640	829.6200	888.2280	791.9505	849.0735	895.9005	376.0020	178.0515	329.4720	487.1295
16	3,107.0655	881.7435	871.0020	918.8190	879.7140	785.5155	837.6885	825.4620	351.7965	180.2295	307.8900	465.4485
17	2,410.8480	950.5980	866.7945	923.3235	868.4775	787.6935	838.5300	802.2465	345.0645	179.1900	317.1960	457.9245
18	1,774.5255	1,048.9050	876.1500	909.1170	857.2410	782.1000	798.9795	739.3320	342.9360	180.2295	1,081.1790	436.2040
19	1,413.3735	1,005.0480	873.7245	911.2455	892.1880	807.7410	799.4745	701.7615	333.2340	183.4470	2,130.6780	420.7500
20	1,294.2270	940.8465	918.9675	922.0860	869.9130	806.8995	769.8735	673.4475	324.5715	205.1775	2,043.8550	397.5840
21	1,141.2720	930.4020	740.2230	913.2255	878.2290	840.0150	754.1820	671.9625	297.6435	504.9000	1,313.0370	400.3065
22	1,081.7235	924.6105	784.1295	912.0375	885.4560	927.4320	764.5275	740.3220	303.6825	332.6400	962.7750	426.3435
23	1,068.4080	948.7665	853.8255	911.2455	865.9530	948.9645	793.4850	723.5910	287.8920	408.5235	722.0565	465.3000
24	1,046.9250	955.4985	822.7890	902.7315	845.4600	885.3570	821.5515	661.4685	273.8340	355.8555	616.6710	1,054.2510
25	928.0755	942.2325	853.7760	906.5925	842.3910	887.7330	845.4600	647.8560	260.9640	324.8685	591.8715	751.4100
26	944.9550	932.2830	861.6465	894.9600	828.5805	874.0710	848.6775	622.7595	248.9850	321.4035	542.8665	670.8735
27	902.5820	946.5390	843.1830	902.6820	825.3185	863.6265	843.4305	573.2090	250.8165	319.0275	506.0880	590.8320
28	846.2025	931.5405	841.7475	908.5725	803.5335	828.7785	956.2410	564.8445	245.9160	306.2565	463.7160	548.7075
29	882.1395	914.0175	842.3910	905.2065	....	814.2750	1,147.7070	546.9750	248.6390	304.1775	435.2535	507.1275
30	827.7390	890.2080	849.3210	893.0295	....	798.8805	1,239.2325	538.4115	243.1440	303.0390	421.1955	528.2145
31	832.0455	....	855.3105	898.3260	....	775.9125	....	504.1080	....	281.3085	483.5655	....
Total	40,872.9415	26,596.5975	26,822.5155	27,642.6315	24,688.9220	25,162.1865	26,017.6455	29,590.4565	11,013.7995	7,835.3550	18,853.7580	15,353.2270

Summary.—Duty of water under all canals from Salt River for year ended September 30, 1900.

Approximate total area irrigated in 1900	acres	113,000.00
Discharge of river	acre-feet	279,900.14
Discharge per acre irrigated	do	2.48
Estimated loss from waste, seepage, and evaporation, 20 per cent	acre-feet	.50
Depth of irrigation	feet	1.98
Rainfall	foot	.30
Total depth of water received by land	feet	2.28
Area served by a continuous flow of 1 cubic foot per second	acres	292.25
Area served by a continuous flow of 1 miner's inch	do	7.55

IRRIGATION AT THE ARIZONA EXPERIMENT STATION FARM

By A. J. McClatchie,

Professor of Agriculture and Horticulture, University of Arizona, and Agriculturist and Horticulturist of the Arizona Experiment Station.

LOCATION AND SOURCE OF WATER SUPPLY.

The farm of the Arizona Agricultural Experiment Station is situated 2 miles northwest of Phoenix, just below the Maricopa Canal. It receives its irrigation water from this canal and from the Grand Canal, which in this part of the valley runs only about a half mile above the Maricopa Canal. One object in obtaining water through both canals is to bring the "runs" nearer together. When the river is low, water is delivered to users much of the time but once in eight days, and small plants are liable to suffer during hot weather. Having water delivered through two canals enables a farmer to irrigate strawberries, garden vegetables, and other shallow-rooted crops every four days. This arrangement has been especially necessary during the past summer, when water has been very low.

SOIL.

The soil of most of the station farm is a clayey, gravelly loam, underlaid with gravel. The loam is 5 to 6 feet deep and the gravel stratum about 8 feet thick, beneath which lies a stratum of fine clay nearly 20 feet thick. On a portion of the farm the loam is overlaid with a fine adobe, the stratum varying in thickness from a few inches at one side of a 6-acre field to 6 or 8 feet at the other side.

Neither the loam nor the adobe permit of rapid percolation, hence all the soils of the farm take irrigation water rather slowly. The adobe soil is moistened more slowly than the loam and retains its moisture longer. Both become very hard if not cultivated at the

proper stage of drying, and the adobe soil cracks as it dries. The period during drying in which the adobe soil can be cultivated is shorter than in the case of the loam.

RAINFALL DURING THE YEAR.

The following is the precipitation affecting crops grown during the past year, as recorded at the farm:

Rainfall at the Arizona Experiment Station farm, October, 1899, to September, 1900.

	Inches.
October 11–14	0.34
November 14	.42
November 22	.06
December 18	.12
January 4	.10
March 13–14	.20
March 25	.03
April 5	.56
April 28	.39
May 5	.10
July 20	1.30
Total	3.62

With the exception of the rain of July 20, which fell when no crops of importance were benefited, there was not a sufficient amount of precipitation during any one storm to be of any considerable benefit to crops, through their roots at least. The rains of October, November, March, and April wet the soil to a depth of 1 to 2½ inches, and in some cases would benefit shallow-rooted crops, such as grains and small vegetables. The principal local value of these light rains is a temporary raising of the humidity of the atmosphere, thus checking evaporation and causing more of the irrigation water to be available to crops. Rain falling just after the irrigation of a field, or during its irrigation, usually helps the crop more than that falling between irrigations. In the latter case the light rains, such as we commonly have, simply moisten the upper inch or two of the soil, the warm weather that follows drying this surface out in a short time and leaving it baked. The crop is then worse off than if the soil had been left mellow. If a rain can be followed with an irrigation, that the moistening of the soil may be continued downward to the moisture below, then the rain may be made to supplement irrigation, and thus be a benefit. In the case of cultivated crops a light rain makes cultivation necessary, without adding to the supply of water at the roots of the crop.

For the above reasons, little of the rain that fell during the year should be counted as part of the amount consumed in growing the crop.

WATER APPLIED TO CROPS GROWN.

A beginning was made during the past year in keeping a record of the amount of water applied during the development of each crop. Unfortunately, the farm is not so situated that the measurement and division of the water that flows upon it is an easy task. The fall of the ditch leading to the farm and the ditches upon the farm is too slight to make the use of Cippoletti weirs possible. Hence it has been necessary to measure the water in boxes placed at the same level as the bottom of the ditches. The triangular shape of the farm has increased the difficulties. However, it is believed that a fairly accurate record has been kept and that a close approximation to the water actually applied has been obtained.

All of the crops tabulated below were irrigated by furrows, except part of the wheat.

Water applied to crops grown.

Crop.	Date of planting.	Date of first irrigation.	Date of last irrigation.	Number of irrigations.	Depth of water applied.	Date of harvesting.	Yield per acre.
					Feet.		*Tons.*
Barley hay	Nov. 7	Nov. 10	Mar. 18	3	1.6	Apr. 8	4.2
Wheat hay:							
Flooded	Nov. 10	Nov. 11	Mar. 19	4	2.1	Apr. 20	3.4
Furrowed	do	Nov. 10	do	4	2.1	do	3.5
Cowpea hay	June 6	June 9	Sept. 9	9	3.8	Sept. 19	3.6
Wheat (grain)	Nov. 4	Nov. 5	Apr. 14	4	2.2	May 10	1.2
Sugar beets	Dec. 26	Apr. 1	June 26	5	2.5	July 30	14.5
Do	Jan. 23	Apr. 8	July 15	5	2.5	Aug. 10	10.5
Potatoes	Jan. 17	Feb. 17	May 2	4	2	May 25	2
Do	Feb. 7	do	do	4	2	May 31	1.6
Watermelons	Mar. 17	Mar. 29	July 15	13	3.2	July —	15
Cabbage	Aug. 11	Sept. 15	Feb. 25	16	5	Jan.-Mar	7
Do	Sept. 29	Nov. 22	May 9	16	5	Mar.-May	6.2
Onions	Sept. 16	Sept. 16	July 11	29	6.2	July —	2.6
Green peas	Nov. 28	Dec. 10	Mar. 22	6	2.4	Apr. —	2.2
Peaches	1892	Dec. 20	Mar. 5	10	3.4	May-Sept	3.8
Apricots	1892	do	do	10	3.4	May —	5
Grapes	1892	Feb. 2	July 15	6	2.8	July-Oct	8.2

In the above table, in most cases, there is included in the amount of water applied to produce the crops that applied previous to plowing the land preparatory to planting. This amount was usually about 0.6 of a foot. To be sure, much of it would be lost before the crop would be sufficiently developed to begin to use it, but this irrigation previous to plowing is in most cases a necessary part of our farming operations, and the water thus used should be counted as part of that necessary for producing any given crop.

The atmospheric conditions seemed to be unfavorable for the proper development of many crops last spring, causing low yields regardless of the amount of water applied. Hence many of the yields given, especially of vegetables, can not be considered indicative of what the same amount of water would produce during an average season. Owing to the shortage of water, alfalfa and many other forage crops were not harvested in sufficient quantities to make the records of water used on them of value.

GRAINS.

It will be observed that the amount of water used in growing grains is comparatively small. This is due to the time of year during which these crops are grown here. The summer being too hot for them, they are grown during the cool part of the year, the most of the growth being made from January to April, when evaporation is comparatively slow. Crops of grain are sometimes grown with the application of much less water than given in the above table. It is necessary either to irrigate the soil thoroughly before plowing, or irrigate soon after sowing the seed. With one irrigation subsequent to this, a good crop can often be grown in soil retentive of moisture, the total amount applied not having exceeded 1 foot. This possibility of growing grain here during the cool part of the year enables us to produce a crop with less water than in a cooler, less arid region, where the crop is grown during the warm part of the year.

Most of the grain crops grown the past year were irrigated through furrows made by a compound roller and furrower devised for the purpose. The seed was sown broadcast on level soil, and the field then furrowed and rolled at one operation, the seed being thus covered about one-half inch deep. The furrows were 2 feet apart, and the intervening level strips about 15 inches wide (Pl. VIII, fig 2). Water was turned down the furrows and permitted to run until the soil was uniformly moistened. The work of irrigating was much less than by the ordinary method of flooding between ridges and the work of seeding was no greater. The principal advantage during the past season seemed to be in the more uniform stand obtained and the more rapid early growth, due to the surface of the soil not baking between the furrows. The final growth and yield were only slightly better than on the flooded areas. The year before there was a difference in yield of over 30 per cent in favor of the furrowed plat. This was probably owing to a difference in the season. The disadvantage of the furrowing system is the unevenness of the surface when a mower or harvester is used. On the whole, the system is of doubtful utility in growing grains under our conditions.

COWPEAS.

The amount of water necessary to grow a crop of cowpea hay is so great, as compared with the amount necessary to produce the same amount of alfalfa hay, a nitrogenous forage of equal value, that its production can scarcely be profitable in any part of the Territory where the amount of water used is a consideration. The need of this great amount of water is due to the fact that the plant must pass through all of its stages from germination to maturity during the warm part of the year, when the loss of water from the luxuriant foliage and from the soil is rapid. The same amount of forage produced

during the cool part of the year would not require much over half the amount of water needed during the summer.

SUGAR BEETS.

This crop makes the most of its growth during the cool part of the year, and can be grown with a comparatively small amount of water. Beets do best if planted during the autumn or winter (preferably during September or December and January), in any case making most of their growth before June. During ordinary years, the greater yield will be obtained with the same amount of water, the earlier they are sown after the coldest weather is past. Last year the coldest weather occurred before Christmas, and the beets sown December 26 produced better results than those sown later and given the same amount of water. The year previous, those sown during January produced a larger yield than those sown during either December or February and given the same amount of water. The same year a yield of nearly 10 tons per acre was secured by the use of about 1 foot of water previous to sowing the seed, and of about 0.4 of a foot applied about two and one-half months afterwards—1.4 feet in all. This was in a fine adobe soil quite retentive of moisture. To produce the same crop in a gravelly porous soil required the use of nearly 3 feet of water.

POTATOES.

This crop, being grown principally during early spring, is produced with a very small quantity of water. If about half a foot of water is applied before planting, and the planting is done during January or early February, no more water need be applied until the plants have attained some size. Two irrigations of 0.4 to 0.5 of a foot while the crop is growing, making only about 1.5 feet in all, are sufficient many years to produce a good crop in most soils. The tendency is to apply too much water and to give too little cultivation. Two feet of water and proper cultivation will produce a better crop than 3 to 4 feet of water without cultivation.

It will be observed that the potatoes planted January 17 gave a fourth greater yield than those planted three weeks later and given the same amount of water. A season having a less mild winter would probably have given different results. The previous year one and three-fourths times the yield of the January plat was secured from a plat planted February 20 in similar soil, the amount of water applied being about the same as this year. As a rule the sooner potatoes are planted after the coolest weather is past the greater will be the yield secured with the use of a given quantity of water. If the planting is delayed until April, for example, a given amount of water produces less than a third the yield that would result from an early February planting.

WATERMELONS.

While watermelons, muskmelons, pumpkins, and squashes require a large number of irrigations during their growth the amount applied to the crop is not correspondingly large, as is shown by the record of the watermelon crop grown during the past year. This is due to the distance between the rows, and the fact that during the early part of the growth of the plants only the furrow along which they are planted is moistened, the usual method of starting them being to make furrows 6 or 8 feet apart, run water through them to moisten the sides, and then to plant the seed on the margin. Ordinarily no further irrigation is necessary until after the young plants appear. A moistening of the furrows twice a month carries the crop along for about two months, after which more frequent and more copious irrigations are necessary. Thus, during the first half of the life of the crop only a small portion of the soil is kept moist, and at no period of its growth is all the surface completely moistened. Furthermore, the vines grow so rapidly that undoubtedly a larger portion of the water is used by the plants and a smaller portion lost from the soil than in the case of many crops. The covering of the surface by the vines would also cause less loss from the soil. Also, the transpiration of moisture from the surface of the fruit and leaves of these plants is slow. For the above reasons a crop yielding a product consisting largely of water is produced with a surprisingly small amount of it.

CABBAGE.

In computing the water used in producing this crop no account was taken of that used in the seed bed. While the soil of the seed bed was kept constantly moist, when the water used is counted as spread over the area covered by the plants when set in the field, the amount is quite small. While cabbages are grown during the cool part of the year, when evaporation is comparatively slow, yet the facts that the plants do not shade the soil, much moisture thus being lost by evaporation, and that they are shallow rooted, thus requiring frequent irrigation, contribute to increase the amount of water needed to produce a crop. Also, in order to thrive, cabbages require a moister soil than many crops.

ONIONS.

The growing of onions involves the use of much water, as well as the expenditure of much labor. Though they are shallow rooted and do not require that the soil be deeply irrigated, they must be irrigated through such a long period—about ten months—that a large amount of water must be applied to produce a crop. A large percentage of this is lost by evaporation. It will be observed that only about 0.2 of a foot was applied at each irrigation, only enough to wet the soil 8 to

10 inches deep. Nearly all the water of the upper 2 or 3 inches and much that reached the soil below this stratum would be lost by evaporation.

PEACHES AND APRICOTS.

These fruits are similar in character and require about the same kind of soil and the same amount of water. When the soil is of the proper character the roots penetrate to great depths, enabling the trees to thrive though the surface stratum be quite dry. In the station orchard their roots are abundant at a depth of 12 to 16 feet, and many of them penetrate to a depth of more than 20 feet. This characteristic makes it possible to store in the soil much, if not all, of the water needed to produce a good crop. As will be seen by a reference to the table, all of the water used by the trees during the past season was applied from December to March 5, while the trees were dormant above the surface. That they were not dormant beneath the surface was shown by an examination made February 20, revealing that at a depth of 10 to 16 feet, even, young roots 3 to 6 inches long had already grown.

The trees made a very vigorous growth and bore a heavy crop of fruit without irrigation from early March until November. The previous year they were irrigated but once between March 29 and December 20. Each of the two years the results were highly satisfactory in growth and appearance of trees and in the size and quality of the fruit. Previous experience indicates that the same amount of water applied during spring and summer, as is the usual custom, would not have produced equal results. The year preceding the two past years a larger amount of water was applied during the period of growth without producing results nearly so satisfactory. During the past year an orchard upon another farm received over two-thirds as much water as this orchard, and at the end of the season showed very little growth and fruit of inferior size.

This difference in the results obtained by applying a given amount of water to one orchard during the winter and the same amount of water to another during the spring and summer is due to several causes. In the first place, the greater abundance of water during the winter enables the grower to apply a large amount of water during a short period of time, thus saturating the soil to a great depth with little loss of water by evaporation. The trees being dormant, no injury is done them by keeping the soil supermoistened or by letting the surface bake. Hence cultivation need not follow irrigation, as is the case in summer, and a very small percentage of water is lost by evaporation. In the summer a large percentage of the water applied escapes directly from the soil without passing through the trees. This is the case whether the surface is cultivated (as should be done) and the upper few inches lose all their water as a result, or the soil is left

to bake (as should not be done), and not only does the surface become hard and dry, but a large amount of water passes up from below through the baked soil. If water were available in abundance during the middle of the summer, it would probably be wise to apply about a foot in as short a time as possible and then follow the irrigation with a thorough plowing, as in the spring after the winter irrigation. Frequent summer irrigations are, however, decidedly inadvisable under our conditions, provided the soil is fairly deep.

Aside from the difference in the results obtained and the amount of labor involved, it should be taken into consideration that the water available during winter has a much less value on account of its comparative abundance than has the water available during the summer. Even if a greater amount were used in winter irrigation, this would still be the cheaper method.

GRAPES.

About three-fourths of the water used by the vineyard was applied during the latter part of winter, before growth began. As the roots do not penetrate to such great depths as do those of peach and apricot trees, it is best to apply some water during the summer, but the larger part can be, and in most cases had better be, applied during winter. It will be seen that a large amount of green fruit is produced in a vineyard by the use of a moderate amount of water.

INFLUENCES AFFECTING DUTY OF WATER.

The duty of water may be expressed in several ways—as the depth to which all the water applied would cover the land irrigated by it, as the number of cubic feet applied per acre, or as the number of acres a stated flow of water will irrigate. Whether stated in one or the other of these ways, the duty of water is influenced by a great many factors, chief among which are (1) character of season, (2) season of year crop grows, (3) time of year water is applied, (4) method of application, (5) the subsequent treatment of the soil, (6) the depth to ground water, and (7) the character of the soil.

CHARACTER OF SEASONS.

The amount of water needed per acre for a given crop will vary with the character of the season as to temperature, relative humidity, air movement, and rainfall. In our region the last two factors do not commonly exert a great influence on the amount of water used. We have few high winds that dry out the soil surface rapidly, and the few inches of annual rainfall are usually, as has been stated was the case during the past year, so scattered throughout the year as to have comparatively little effect upon irrigation. The seasons differ considerably as to temperature and the relative humidity of the atmosphere. During June and July, 1900, for example, the air was

unusually warm and devoid of moisture, the humidity running as low as only 3 to 10 per cent at times. Air in this condition absorbs moisture from the soil and from crops very rapidly, increasing in a marked degree the amount of water needed to keep crops in a flourishing condition.

SEASON OF YEAR CROP GROWS.

As has been stated, the growing of several of our crops during the winter season, when the loss of water from the soil and from the leaves of plants is comparatively slow, has a marked effect on the duty of water in our valley. Grains, sugar beets, potatoes, and a large class of garden vegetables can consequently be grown with less water here than in regions where the severity of the winters necessitates the growing of these crops during the summer. Crops grown here during the latter season must make a rapid growth and yield heavily in order to be profitable.

TIME OF YEAR WATER IS APPLIED.

The time of applying water affects materially the total amount that will be needed to produce a good yield. In the case of grain and sugar beets the application of too much water early in their growth may result not only in the loss of much water from the soil, but in the formation of surface roots instead of deep-penetrating ones, which will necessitate the frequent application of water subsequently. Withholding water during the early stages of growth and applying it during the latter stages requires a small amount to produce a crop.

In the case of fruit trees, the application of water during the cool part of the year results in less loss by evaporation and a consequent saving in the amount applied.

METHOD OF APPLICATION.

The application of water through furrows whenever practicable saves the loss of much water by evaporation from the surface. Not only does the water penetrate into the soil deeper, but a smaller percentage of the surface of the soil becomes "baked" as it dries. A baked surface requires irrigation to soften it. In irrigating orchards and most crops, except alfalfa meadows and pastures, the furrow system will result in a saving of water. The application of small amounts at one irrigation is ordinarily wasteful. The smaller the amount applied at one time the larger will be the percentage of loss by evaporation. If, for example, only the upper 2 or 3 inches of the soil are moistened, nearly all of the water applied will escape without passing through the plants growing in the soil. If the upper foot is moistened, probably one-half the water applied will pass through the plants. If the upper 2 feet are moistened, then a still larger percentage will pass through the plants. The object of all methods of irrigation is to get

as much of the irrigating water to pass through the plants as possible, and let as little of it as possible escape by seepage or evaporation.

SUBSEQUENT TREATMENT OF SOIL.

In the case of all tilled crops, the treatment of the soil subsequent to irrigation has a marked effect on the loss of water and the consequent frequency of irrigation. If the soil be permitted to bake instead of being cultivated as soon as dry enough, the crop will need another irrigation much sooner. Cultivation not only breaks up the capillary tubes through which moisture from below makes its way to the surface, but forms over the surface a mulch that prevents rapid evaporation. A test in May, 1900, illustrates this point. A portion of a field irrigated March 5 had been left uncultivated. Samples of soil were taken May 23, and the percentage of water in each foot of the upper 5 feet determined. The results were as follows:

Percentage of moisture in cultivated and uncultivated soils.

Depth.	Cultivated.	Uncultivated.
	Per cent.	*Per cent.*
First foot	7.3	3.8
Second foot	12.6	8.1
Third foot	15.6	10.5
Fourth foot	15	11.6
Fifth foot	12.1	11.7
Total	62.6	45.7

It will be seen that as a whole the upper 5 feet of soil in the cultivated area contained over a third more water than the same depth of soil in the uncultivated area. But when only the available water is taken into consideration the difference is much greater. In such a soil as the above at least 5 per cent would be left in the soil after the rootlets had removed all they could. Making this deduction, the soil in the cultivated area contained about twice as much available water as that in the uncultivated area. The loss of water from the latter, from March 5 to May 23, was about two-tenths of a foot in depth greater than from the cultivated area. Considerable of this loss was through the weeds that grew where the soil was uncultivated. Not only do weeds require water for their increase in size, but water is continually evaporating from the surface of their leaves. While they may shade the surface of the soil so as to check evaporation there, the evaporation from their leaves is much more rapid than it would be from the surface of the unshaded soil if it were properly cultivated.

DEPTH TO GROUND WATER.

In some parts of the Salt River Valley, as elsewhere, the ground water is so near the surface that the roots of alfalfa and fruit trees obtain a considerable amount of the water they use from that source.

Under these conditions the amount needed by irrigation would be manifestly less. In the vicinity of Tempe, where the ground water is within 6 to 15 feet of the surface, all crops, especially deep-rooted ones, require less water than on the station farm, where the ground water is 35 to 40 feet below the surface.

CHARACTER OF THE SOIL.

The character of the soil affects considerably the duty of irrigating water. The amount of water a soil will hold and the rapidity with which the water leaves the soil determine the amount and frequency of the irrigations necessary. A heavy—that is, a fine—soil has a greater water-holding capacity than a coarse, sandy one, and will lose what it has absorbed at a slower rate than the latter. These two factors—capacity and retentiveness—will affect, naturally, the number of irrigations a crop growing in any particular soil will need. Frequency of irrigation results in a greater loss from evaporation, since nearly all the water applied to the surface is lost.

CALIFORNIA.

DUTY OF WATER UNDER GAGE CANAL, RIVERSIDE, CAL., 1900.

By W. Irving, C. E.

During the past year the weather has been very favorable for the continued growth of the citrus trees and for the development of the fruit, the fruit being, on the average, two sizes larger than at this time last year.

The irrigation of the lands under the Gage Canal has been practically continuous during the year, as the rainfall was not in sufficient quantities at any one time to take the place of a regular irrigation, although the irrigations were interrupted from time to time owing to these storms.

The following table gives the rainfall for the year:

Rainfall record at Camp Arlington, Arlington Heights, November 14, 1899, to October 20, 1900.

Date.	Rainfall.
1899.	*Inches.*
November 14	0.21
November 16	.04
November 17	.14
November 21	.18
	.57
December 16	.10
December 17	.20
December 29	.11
	.41
1900.	
January 3	.97
January 4	.02
January 5	.01
January 25	.01
	1.01
February 1	.01
March 4	.55
March 20	.14
March 23	.26
	.95
1900—Continued.	*Inches.*
April 3	0.08
April 7	.01
April 21	.46
April 22	.02
April 27	.17
	.74
May 4	.42
May 5	.67
May 10	.09
May 11	.11
	1.29
October 13	.22
October 20	.06
	.28
Total rainfall	5.26

The flow of water in the canal was reduced to a minimum of 104 inches on the 4th of January, and remained below 1,000 inches until the 28th of the same month, the fall of rain and the picking of the fruit during this interval doing away with the necessity of any greater

flow. From January 28 the flow of water was gradually increased to meet the needs of the irrigators until it reached an average flow of 1,400 inches during the months of September and October, the highest point reached being a flow of 1,448 inches October 21, since which date, the need for water becoming less owing to cool weather and occasional rains, the flow over the whole system was gradually reduced to zero at times during the winter season.

The total average flow of irrigation water over the whole system for the season was equal to 2.23 acre-feet per acre, which, with a rainfall of 0.44 of a foot, makes a total depth of 2.67 feet received by the land.

This average depth is 0.22 foot less than what we have determined as the "duty of water" in our system, but as there are included in the total acreage watered about 500 acres of newly planted lands and about the same acreage not yet arrived at full maturity, the practical duty is nearly equal to the theoretical of 2.89 acre-feet per acre.

DISTRICT NO. 1.

The acreage of district No. 1 is practically the same as during last year, there being a total of 3,614 acres under cultivation at present, which, with the prevailing duty of water of 1 inch to 5 acres, gives this land a water right of 722.8 miner's inches continuous flow. The water used daily in the district is shown in the following table. The measurements are given in miner's inches.

Water used in district No. 1, under Gage Canal, November 1, 1899, to October 31, 1900.

Day.	1899.		1900.									
	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.
	Miner's inches.	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*
1	515	363	433	613	565	606	486	741	719	683	729	689
2	515	382	388	653	588	620	571	623	739	710	735	717
3	577	371	313	567	657	647	662	776	702	711	767	690
4	614	405	104	532	701	671	603	850	725	769	743	710
5	563	462	304	687	610	651	269	680	736	777	774	700
6	654	N. wind.	85	713	558	654	287	711	733	742	759	710
7	759	379	160	718	648	679	214	697	720	745	729	775
8	798	442	146	767	577	648	300	686	760	745	733	669
9	763	488	52	775	594	637	232	689	748	718	694	688
10	722	426	114	779	571	624	432	761	746	699	698	658
11	741	459	183	722	566	719	405	812	752	729	694	683
12	634	626	126	691	520	708	458	731	720	676	705	674
13	670	639	121	657	582	724	345	678	694	713	684	649
14	580	641	104	649	606	711	505	702	694	715	667	624
15	779	708	116	677	689	719	536	670	718	709	653	638
16	558	643	96	686	729	703	592	736	668	693	704	703
17	482	195	164	722	684	721	660	759	742	694	722	740
18	553	373	114	685	579	723	708	781	719	732	659	690
19	458	563	292	650	590	685	733	775	695	764	721	697
20	466	569	309	680	583	654	688	745	742	754	715	617
21	431	626	180	631	583	581	705	748	751	750	789	557
22	292	646	147	608	645	598	724	748	703	767	712	484
23	420	681	166	605	593	630	645	706	656	740	643	542
24	435	620	172	482	538	545	689	710	647	728	606	533
25	486	569	388	570	506	592	709	767	722	655	637	571
26	392	489	638	629	560	659	702	641	761	661	608	600
27	410	611	470	653	539	668	714	734	749	736	695	568
28	419	570	797	622	555	625	665	783	730	723	698	569
29	424	429	591	....	498	599	749	745	754	740	782	588
30	372	514	511	....	509	522	699	715	729	716	748	553
31	....	460	516	....	567	....	716	....	703	642	....	523
Total	16,482	15,349	8,299	18,318	18,290	19,523	17,403	21,990	22,377	22,336	21,143	19,809
Monthly averages	549	514	238	654	590	651	561	733	721	714	704	639

Duty of water in district No. 1, under Gage Canal, 1899–1900.

Area irrigated	acres	3,614
Water used	acre-feet	8,779.64
Depth of water used in irrigation	feet	2.43
Depth of rainfall	foot	.44
Total depth of water received by land	feet	2.87

For the irrigation of this district we had a daily average flow of 606 inches for the year. This flow of water gives an average duty of 1 inch to 5.96 acres, or a total depth over the whole district of 2.43 acre-feet, to which we add the total rainfall of 0.44 foot, making a total depth of 2.85 feet of water received by the land.

District No. 1 is the oldest territory under the Gage Canal, the first planting commencing in the year 1887, hence the trees have now more generally reached a condition of maturity and require nearly their full allowance of water.

DISTRICT NO. 2.

Considerable planting has been done in this district during the past year, and the total acreage under cultivation is 3,237.84 acres. For the irrigation of this land we have an average flow of 474 inches. This amount in continuous flow equals a duty of water of 1 inch to 6.83 acres, or 2.11 acre-feet. To this we add the rainfall, 0.44 foot, making the total depth of water received by the land 2.56 feet.

The following table shows the daily use of water.

Water used in district No. 2, under Gage Canal, November 1, 1899, to October 31, 1900.

Day.	1899. November.	1899. December.	1900. January.	1900. February.	1900. March.	1900. April.	1900. May.	1900. June.	1900. July.	1900. August.	1900. September.	1900. October.
	Miner's inches.	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*
1	490.40	334.16	485.86	535.84	464.84	523.24	680	372.02	416.40	567.83	587.71	590.63
2	541.36	363.46	487.92	568.18	486.31	489.36	499.04	390.22	470.47	540.90	579.25	589
3	536.27	348.12	Rain.	560.91	430.21	469.87	427.04	391.02	479.50	556.94	527.86	599.63
4	505.86	308.47	Rain.	503.03	391.10	470.61	478.15	362.80	499.09	514.34	570.44	571.95
5	458.78	313.94	Rain.	446.09	535.95	477.80	258.53	407.02	484.25	541.32	630.50	572.13
6	489.07	340.84	75	425.27	548.31	447.72	Rain.	430.90	493.25	572.50	582.15	595.22
7	426.52	481.56	80	419.89	458.73	437.80	461.85	454.71	450.02	536.11	571.34	579.25
8	380.80	480.04	90	341.86	572.27	440.68	641.34	453.29	435.81	552.34	598	634.63
9	391.40	509.61	100	338.75	538.90	419.13	800.75	406.18	456.68	568.55	626.56	633.04
10	399.64	549.70	100	331.24	608.61	480.56	625.65	413	473.63	554.22	652.52	642.67
11	389.77	533.72	100	406.27	582.54	393.90	388.82	433.47	478.11	564.98	649.37	615.63
12	408.17	550.50	150	450.21	569.89	408.38	806.38	447.57	479.84	593	645.50	606.34
13	413.36	512.61	75	457.27	528.29	365.82	692.81	478.40	516.15	603.15	651.21	667.38
14	401.15	499.67	60	477.65	472.67	373.27	692.46	461.35	492.62	574.51	648.65	675.46
15	Rain.	453.62	175	449.70	397.15	341.60	604.62	468.09	496.17	577.52	624.67	674
16	354.60	474.75	200	422.27	398.82	393.69	568.11	372.42	519.54	595.77	606.79	628.34
17	299.60	Rain.	150	391.11	462.37	388.84	488.74	393.39	497.36	609.73	577.34	619.78
18	299.60	467.92	200	446.82	479.98	330.15	388.57	395.55	511.18	563.56	636.11	657.21
19	419.60	562.66	150	448	479.94	334.28	333.98	432.56	554.63	566.32	589.46	653
20	419.60	570	195	454.55	474.29	362.41	535.69	429.17	493.25	557.94	612.72	716.96
21	384.62	507.68	170	509.21	459.07	435.45	447.45	436.17	533.37	532.20	545.75	811.46
22	Rain.	481.29	350	525.71	412.31	432.91	394.25	463.75	531.52	561.59	595.34	860.92
23	264.57	423.11	450	524.41	467.13	458.63	462.42	367.13	555.96	537.13	642.63	773.17
24	241.04	415.39	450	633.48	502.90	513.15	494.25	417.28	552.86	592.27	630.11	686.97
25	260.02	356.10	450	552.15	556.68	472.71	414.75	423.58	539.05	654.05	657.46	613.05
26	270.45	383.35	200	504.47	541.65	448.76	422.21	542.17	527.88	641.24	668.71	582.59
27	311	366.23	350	479.05	519.68	404.87	400.65	489.17	543.07	578.06	593.75	595.42
28	318.72	404.77	357	463.40	516.93	429.42	481.19	387.79	553.57	572.49	586.34	627.50
29	315.24	463.36	455.10		564.21	560.52	447.90	444.29	503.05	592.42	553.29	662.96
30	316.79	486.75	526.20		543.45	536.28	427.12	460.82	579.35	613.85	588.67	708.71
31		477.31	540.36		513.63		417.98		595.90	657.69		703.20
Total	10,708	13,420.69	7,172.44	13,066.79	15,473.81	13,040.81	15,182.90	12,825.28	15,708.48	17,844.52	18,230.20	20,158.20
Monthly average	356.31	431.09	255.77	466.21	498.64	434.63	487.23	427.05	506.73	581.57	607.64	650.50

Duty of water in district No. 2, under Gage Canal, 1899–1900.

Area irrigated	acres	3,237.84
Water used	acre-feet	6,855.71
Depth of water used in irrigation	feet	2.12
Depth of rainfall	foot	.44
Total depth of water received by land	feet	2.56

In this district the planting was commenced in the year 1891 and has been continued from year to year, more or less, since that time (360 acres planted during the present year), so that a large proportion of the total trees planted has not yet reached maturity, and consequently does not require the full amount of water for its irrigation.

DISTRICT NO. 3.

The acreage of district No. 3 has been increased during the year from 530 to 650 acres, the full water right being 130 miner's inches continuous flow, or 2.89 acre-feet per acre.

With the exception of a few weeks during the winter months, the flow of water to this district has been continuous during the year.

The irrigation water alone has been a daily average of 74 miner's inches during the whole season, making a duty of water of 1 inch to 8.78 acres, or 1.63 acre-feet per acre. If we add, as before, the rainfall of 0.44 foot, we have a depth of 2.07 feet. The time of the use of water in this district is shown by the following table.

Water used in district No. 3, under Gage Canal, November 1, 1899, to October 31, 1900.

Day.	1899.		1900.									
	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.
	Miner's inches.	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*
1	39.60	65.84	99.14	64.16	97.16	24.76	2.00	99.98	80.60	62.17	100.29	109.37
2	34.64	66.54	99.08	72.82	79.69	58.64	111.96	100.78	59.53	81.10	86.75	102.06
3	18.73	71.88	47.48	26.09	93.79	75.13	106.96	58.98	97.50	94.06	104.14	88.37
4	34.14	81.53	......	55.97	88.90	68.39	90.85	61.20	103.91	73.66	85.56	101.05
5	41.22	86.06	......	79.91	76.05	57.26	94.47	92.98	102.75	92.68	.50	110.87
6	40.93	84.16	(1)	74.73	74.69	79.28	72.10	70.10	86.75	86.50	56.85	81.78
7	35.48	88.44	(1)	80.11	100.27	64.20	2.15	49.29	88.98	80.89	93.66	80.75
8	34.20	69.96	(1)	104.14	63.73	65.32	96.66	76.71	97.19	98.66	92.00	85.37
9	38.60	20.39	......	99.25	80.10	88.87	86.25	68.82	79.37	89.45	99.44	86.96
10	50.36	51.30	......	102.76	12.39	58.44	117.35	67.00	78.37	108.78	87.48	77.33
11	50.23	51.28	......	84.73	64.46	50.10	113.18	72.53	63.89	93.02	90.63	84.37
12	51.83	69.50	......	100.79	101.11	46.62	27.62	100.43	64.16	108.00	64.50	92.66
13	56.64	70.39	......	98.73	102.71	73.18	107.19	85.60	88.85	89.85	73.79	110.62
14	38.85	40.33	......	86.35	117.33	69.73	108.54	91.65	87.38	113.49	71.35	120.54
15	.40	51.38	......	86.30	94.85	65.40	100.08	52.91	83.83	110.48	95.33	104.00
16	.40	95.25	......	104.73	53.18	59.31	85.89	64.58	81.46	92.23	76.21	73.66
17	.40	51.20	......	99.89	55.63	63.66	82.26	28.61	88.64	78.27	86.66	72.22
18	.40	50.08	......	81.18	96.02	72.35	105.43	53.45	82.82	90.44	109.89	72.79
19	.40	87.34	......	74.00	93.06	71.72	96.02	80.44	68.37	85.68	92.54	71.00
20	.40	83.00	......	78.45	105.71	83.59	64.31	76.83	77.75	104.06	101.28	76.04
21	45.38	79.32	......	72.79	111.93	96.55	98.55	65.83	53.63	94.80	106.25	79.54
22	29.57	85.71	......	79.29	96.69	95.09	104.75	43.25	83.48	67.41	91.66	76.08
23	35.43	76.89	......	83.59	102.87	65.37	58.58	82.87	87.04	69.87	82.37	76.83
24	38.96	91.61	......	80.52	113.10	95.85	57.75	87.72	94.14	95.73	109.89	77.03
25	39.96	93.90	......	90.85	111.82	89.29	98.25	69.42	85.95	115.95	92.54	71.95
26	59.55	93.65	......	79.53	111.35	85.24	82.79	71.83	87.12	118.76	101.29	70.41
27	65.00	94.77	......	80.95	104.32	113.63	102.35	94.83	108.93	95.94	106.25	68.58
28	66.28	70.23	......	95.60	91.07	104.58	99.81	75.21	107.43	93.51	91.66	70.50
29	64.76	86.64	44.90	......	100.79	109.48	98.10	65.71	72.95	98.58	101.71	83.04
30	63.21	62.25	62.80	......	101.55	109.72	94.88	79.18	87.65	90.15	98.33	87.29
31	......	89.69	56.64	......	73.37	......	97.02	......	87.10	101.31	......	87.80
Total	1,070.97	2,260.51	410.14	2,318.21	2,770.19	2,261.19	2,659.10	2,188.72	2,612.52	2,865.48	2,650.80	2,650.80
Monthly average	35.69	72.91	13.23	82.79	89.36	75.37	85.77	72.96	84.27	92.43	88.36	85.50

(1) Water not needed.

Duty of water in district No. 3, under Gage Canal, 1899-1900.

Area irrigated	acres..	650.00
Water used	acre-feet..	1,059.89
Depth of water used in irrigation	feet..	1.63
Depth of rainfall	foot..	.44
Total depth of water received by land	feet..	2.07

In district No. 3 the planting commenced in the year 1895, and has been continued during each succeeding year since that time; consequently a very large proportion of the trees in this district are young and none of the trees have reached full maturity. These conditions account for the smaller proportion of water delivered to this district than to district No. 1.

The following table shows the duty under the whole Gage Canal:

Duty of water under Gage Canal, 1899-1900.

Area irrigated	acres..	7,501.84
Water used	acre-feet..	16,695.24
Depth of water used in irrigation	feet..	2.23
Depth of rainfall	foot..	.44
Total depth of water received by land	feet..	2.67

GENERAL CONCLUSIONS.

The territory above referred to is almost exclusively devoted to the cultivation of citrus fruits, including the orange, lemon, and pomelo, and I may add that this is true of the whole of the Riverside territory, the "Gage Canal system" forming part of the same.

Notwithstanding the occurrence of a series of dry seasons where the natural rainfall has been only about one-half the average, the water supply to the whole of the Riverside territory has been sufficient to maintain all the planted lands in a good, healthy condition, and the trees have matured a larger product than ever before during their history.

It is true, however, that we had to resort to extra means in maintaining the water supply, and consequently entailed greater cost.

In my report of last year[1] I gave the cost for maintenance of canals, water sources, and distribution of water to the lands as being $2.48 per acre. For this year the cost has been $4.24 per acre. This increased cost was wholly due to the fact that about 30 per cent of our total water supply had to be pumped from sources which hitherto had flowed by gravitation.

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

During the year we installed, in the form of gas engines and centrifugul pumps, about 80 horsepower in four units, and raised about 425 miner's inches from an average depth of 18 feet, at a cost of 7.5 cents per inch. The pumps were connected to 10 artesian wells which had ceased to flow during the recent dry seasons, and in pumping the above amount of water the water level was reduced, on the average, to tho extent above stated. The wells above referred to are situated on the margins of our general system, and they were the first to be affected by the general arid conditions prevailing during the last few years.

Up to the present time the rainfall for the incoming season is nearly equal to the average for the whole season in our locality, hence we assume that with the additions we are likely to get during March, April, and May we will be relieved of the cost of pumping during next season.

As previously reported, the only charge made for the use of water under our system is for the current expenditures in maintaining the system and distributing the water to those who acquire a right to it by the purchase of land, at a price per acre, including water in continuous flow in the ratio of "1 miner's inch to each 5 acres of land."

VALUE OF LAND AND WATER.

In district No. 2 the lands yet unplanted are held at a valuation of $400 per acre, including water on the ratio of 1 inch continuous flow to each 5 acres of land. This water right includes, in the first instance, a share to the above extent of an actual body of flowing water, partly freely flowing surface water in the Santa Ana River and partly freely flowing water from developed artesian wells, together with the right of flowage in the Gage Canal and through all parts of the distributing-pipe system, which carries the water to the highest point of each 10-acre lot; also a right in the water sources, consisting of about 468 acres lying adjacent to Santa Ana River, from which to develop additional water for the maintenance of the original amount of water.

The lands planted in the year 1891 to navel oranges have changed ownership during the last two years at the rate of $1,800 per acre. Lands planted in the year 1898 changed ownership a few days ago at $1,000 per acre. From these prices, actually paid in the transfers, one can fairly estimate general prices prevailing at the present time.

In the case where water is sold or transferred in the form of stock in the Gage Canal, exclusive of land, its value has fluctuated between $500 and $1,250 per inch, or in acreage value between $100 and $250 per acre, where 1 inch to 5 acres is assumed as the duty of water. Assuming, then, this latter sum of $250 per acre as the real value of water alone at the present time, the lands without water would be

rated at $150 per acre, but as a matter of fact there seems to be some "magic" about the application of water to lands, as the value of the whole (land and water) is much greater than the sum of the parts. Good lands, without expectation of supply of water, can be purchased in our territory for $20 per acre. The same lands under the flow of some one or other of the canals, and with the prospect of purchasing a water right, are held at $100 per acre. The same after acquiring a water right, say, at $250 per acre, or $1,250 per inch, would be held at $450 per acre. Some lands during the past year under the Gage Canal have been transferred at the rate of $600 per acre, the only improvements over a "state of nature" being a "water right" and a system of distribution carrying the water in pipes to each 10-acre lot.

NEVADA.

IRRIGATION INVESTIGATIONS IN NEVADA.

By J. M. Wilson, *Agent and Expert.*

The investigations here recorded were, for the most part, confined to the vicinity of Reno, in the valley of Truckee River. The work consisted of observations on the methods employed, the volumes used, and the results obtained from the use of water:

(1) On carefully measured plats at the experiment farm of the Nevada State University.

(2) On the farm of James Sullivan, 4 miles east of Reno.

(3) On the lands under the Orr Ditch.

These selections were made in the light of the best information that could be obtained as to what was considered good irrigation practice in this locality.

Measurements were also made of the rainfall and evaporation, and in addition to the work on the Truckee, stations were established in the Humboldt Valley at Lovelocks and Elko for measuring the evaporation. Some of the more important facts gathered in connection with these studies are set down in the following pages.

OBSERVATIONS AT EXPERIMENT FARM OF NEVADA STATE UNIVERSITY.

These investigations were conducted by R. H. McDowell, professor of agriculture and horticulture, assisted by T. W. Clark, foreman of the farm. For convenience in the experiment work of the farm, a portion (15 acres) has been divided into acre plats. The English Ditch, which supplies water, touches this tract at its northwest corner, and at this point the diversion is made and the water measured. The measurement is made over an 18-inch Cippoletti weir. A continuous record of the depth on the crest was kept by an automatic register. The grade of the lateral just above the point where the measuring apparatus is located is quite steep, and to avoid the uncertainties due to velocity of approach the lateral was widened above the weir, so as to make a small reservoir about 20 feet wide and about 30 feet long, with a depth below the crest of the weir of about 2 feet. By this arrangement the water was practically brought to rest before passing over the weir. Two one-fourth-acre plats, each 16 rods long by 2½ rods wide, were used for the experiment. One was planted to Burbank potatoes and the other to White Australian wheat. The soil is a sandy loam underlaid with gravel and bowlders, giving good drain-

age. In quality and depth of soil the two plats are below the average of the farm. The slope of the plat is a little too steep for the most economical application of the water, but the surface is smooth and otherwise favorable.

A matter which was not thought of at first in connection with the experiment came to have considerable significance. The small size of the plats was found to be a serious obstacle in the way of an accurate determination of the water used. It is very difficult to irrigate a tract of this size so as to secure the proper degree of moisture over all the tract and along the boundaries without some of the water escaping into the waste ditches and some being absorbed by the contiguous lands. With larger fields the percentage of such necessary loss is small, but as the size of the tract diminishes the proportion of loss is greatly increased.

Prior to 1897 the field had been used for several years as an alfalfa meadow, and during the seasons of 1897 and 1898 wheat was grown. In 1899 the field was planted to a variety of cultivated crops. I could not learn that any fertilizer had been used for these crops, nor was any used this year.

WHEAT.

The plat was prepared for seeding by plowing to a depth of 7½ inches, harrowing twice, and then rolling.

Eighteen and three-fourths pounds of seed were used on the one-fourth acre. In planting, an ordinary farm drill was used. After seeding shallow furrows were run lengthwise of the plat 30 inches apart. In irrigating, the water was run in these furrows until the spaces between were sufficiently moistened. On account of the excessive slope the water reached the lower end of the furrow before the spaces between were fully watered. To complete the irrigation the flow was continued and whatever water was not absorbed escaped at the lower end of the plat into the drain ditch, and, so far as this crop was concerned, was wasted. The loss was considerable, but the amount escaping could not be accurately determined. The tract received nine irrigations, water being applied as follows:

Water used on wheat, Nevada Experiment Station.

Irrigation.	Time of beginning.	Duration of irrigation.		Water used.
		h.	*m.*	*Acre-feet.*
First	May 16, 9.25 a. m	10	20	0.229
Second	May 17, 7.45 a. m	8	45	.129
Third	June 1, 4.45 p. m	8	45	.149
Fourth	June 18, 8.10 p. m	12	35	.223
Fifth	June 26, 4.30 p. m	13	5	.504
Sixth	July 6, 5.20 p. m	13	50	.290
Seventh	July 14, 5.10 p. m	12	20	141
Eighth	July 25, 8.15 a. m	7	30	.174
Ninth	Aug. 3, 7.30 a. m	6	15	.225
Total				2.064

The total depth applied during the season was 8.256 feet. The wheat was harvested August 15, and yielded 419.5 pounds, or at the rate of 1,678 pounds per acre. This is equivalent to 0.839 tons, or 27.97 bushels, per acre. At 1 cent per pound, or 60 cents per bushel, which is about the market price for a fair quality of milling wheat in Reno at the date of this writing, the returns per acre would be $16.78. This yield is a little above the average for the season in this locality, but it is not up to the yield on good farms in the Truckee Valley in ordinary years.

POTATOES.

The ground was prepared for planting by plowing, harrowing, and rolling, as for the wheat. The variety planted was the Burbank. Planting was done May 5, in rows 36 inches apart, running lengthwise of the plat, and 30 inches apart in the rows. The potatoes were dropped by hand and covered with a shovel plow to a depth of about 4 inches. Two hundred and fifty-two and one-quarter pounds of seed were used, or at the rate of 1,009 pounds per acre, equal to one-half ton, or 16.8 bushels, per acre. The plow used in covering the seed leaves an open furrow between the rows, and in irrigating water is run in these furrows until the space between is moistened satisfactorily. What has been said about the slope and the waste of water on the wheat also applies here. As soon after each irrigation as the soil was in condition for working, the spaces between the rows were cultivated and a new furrow opened for the next irrigation.

The tract received ten irrigations, water being applied as follows:

Water used on potatoes, Nevada Experiment Station.

Irrigation.	Time of beginning.	Duration of irrigation.		Water used.
		h.	*m.*	*Acre-feet.*
First	May 17, 4.30 p. m	16	30	0.184
Second	June 2, 4.50 p. m	13	10	.066
Third	June 4, 5.02 a. m	3	30	.049
Fourth	June 19, 7.45 p. m	11	25	.278
Fifth	June 27, 7.30 p. m	13	30	.778
Sixth	July 7, 5.15 p. m	13	45	.272
Seventh	July 16, 7.30 a. m	6	15	.064
Eighth	July 26, 7.40 p. m	12	20	.105
Ninth	Aug. 3, 1.45 p. m	7	0	.134
Tenth	Aug. 13, 9.30 a. m	5	0	.110
Total				2.045

The total depth applied for the season was 8.16 feet. The potatoes were harvested October 9. The yield from the one-fourth acre was 5,741 pounds, or at the rate of 22,964 pounds per acre, equal to 11.48 tons, or 382.7 bushels, per acre. At $15 per ton, or 45 cents per bushel, which is about market price this season at Reno, the return

per acre would be $172.20. The yield is above the average, though not considered extraordinary for this locality.

The number of waterings on the wheat and potato crops corresponds closely with ordinary farming practice in this valley. As has been indicated, a good deal of the water applied to these plats escaped without passing into the soil. Referring to the tables, it will be seen that several of these irrigations were given in the night, and under these circumstances there was more waste than if the irrigations had been carefully watched. The probabilities are that much of the water escaped into the gravel stratum which lies quite close to the surface of these plats.

RAINFALL.

A record of the rainfall for the season was obtained from the Weather Bureau station at the university grounds, about one-half mile away, and is reported as follows:

Depth of rainfall at Reno during 1900.

	Inches.
January	0.50
February	.27
March	.59
April	1.75
May	.39
June	1.08
July	.18
August	[1].22
September	.67
October	.44
November	1.48
December	.46
Total	[2]8.03

EVAPORATION.

The apparatus for observations on evaporation was established at the station farm May 4, 1900. It consisted of a circular tank 3 feet in diameter and 3 feet deep, set in an excavation 2 feet in depth, with earth banked around it to within 1 inch of the top. At each observa-

[1] The August records at this station were destroyed by fire. The amount given is taken from the record at Verdi, Nev., 12 miles distant, in the same valley, and is approximately correct for Reno.

[2] Equal to 0.669 foot.

FIG. 1.—MEASURING WEIR, SULLIVAN RANCH.

FIG. 2.—MEASURING FLUME AND REGISTER, ORR DITCH.

tion the tank was filled to a point 2 inches below the top. The record of the observations is as follows:

Evaporation record, station farm.

Date of measurement.	Time since last measured.	Depth lost by evaporation.
	Days.	*Inches.*
May 4, 1900		
May 21	17	3¼
June 2	12	3⅛
June 16	14	5
June 30	14	4¾
July 14	14	4⅞
July 28	14	5⅜
August 13	16	[1] 4
August 27	14	3¾
September 10	14	2¾
September 24	14	1¾
October 10	16	1⅞
October 24	14	1⅞
Total evaporation (May 4 to October 24)	173	[2] 42¼

[1] The record for this period at the station was lost. The figures are supplied from observations taken at the Sullivan Ranch.
[2] Equal to 3.52 feet.

A record was also kept of all the water used during the season on the 15 acres of experimental plats, but except in the two cases already discussed no attempt was made to determine the volume used on individual tracts. The total volume used on the 15 acres was 67.92 acre-feet, or an average depth over all of 4.53 feet.

OBSERVATIONS AT SULLIVAN'S RANCH.

The circumstances attending an experiment at the station farm are somewhat different from those applying in farm work. In order that some of the observations might be made under ordinary farm conditions, a record was kept of the water used on 107½ acres, watered by a lateral taken from the Orr Ditch, on the farm of James Sullivan, 4 miles east of Reno. Of this tract 100 acres is alfalfa meadow, 5½ acres were planted to potatoes, and 2 acres sown to wheat. On account of the delay in getting the register, the keeping of the continuous record of the water used did not begin till May 7. The volumes used on these crops in the irrigations which preceded this date are computed from observations made by Mr. Dennis Sullivan, who noted from the beginning of the season the number of inches used and the time required for each irrigation. The measurements were made over a 4-foot Cippoletti weir, and a record of depths was kept by a register similar to the one used at the station farm. Plate IX, fig. 1, shows the weir and evaporation tank.

WHEAT.

On the 5th day of April, after plowing and cultivating with a disk harrow, 2 acres were seeded to wheat. The variety sown was Gypsum, and 125 pounds of seed were used per acre. The soil is a sandy loam and was not fertilized. The field was irrigated 11 times, as shown below:

Irrigation of wheat on Sullivan Ranch.

Irrigation.	Time of beginning.	Duration of irrigation.	Water used.
		Hours.	*Acre-feet.*
First	Apr. 1, 7 a. m	12	3
Second	Apr. 20, 7 a. m	12	3
Third	May 1, 7 a. m	12	3
Fourth	May 10, 7 a. m	12	3
Fifth	May 22, 7 a. m	12	3
Sixth	June 2, 7 a. m	12	3
Seventh	June 13, 7 a. m	12	3
Eighth	June 26, 7 a. m	12	3.01
Ninth	July 5, 7 a. m	12	.79
Tenth	July 18, 7 a. m	12	3.42
Eleventh	July 26, 7 a. m	12	.26
Total			28.48

The total depth of water applied during the season was 14.24 feet. The volume reported is excessive, much of the water applied to the wheat passing to the alfalfa field which lies below. No measurement was kept of the escaping water. The total yield was 2.925 tons, or 1.462 tons per acre, equal to 2,925 pounds, or 48.75 bushels. At 1 cent per pound, or 60 cents per bushel, the returns are $29.25. As before stated, we were not able to establish the register until the season was well advanced. Only the last four irrigations were measured at the weir. The others are computed from Mr. Sullivan's notes as to the number of inches used and the number of hours during which water was applied at each irrigation.

His measurements were made through the boxes used by the superintendent in dividing the water to the shareholders of the ditch.

The water is passed through a 4-inch vertical opening with a pressure of 6 inches above the center of the opening. The volume delivered by each square inch of opening is called an inch. An opening 10 inches wide would deliver 40 inches, one 25 inches wide 100 inches, and one 40 inches wide 160 inches.

POTATOES.

May 21 5½ acres were planted to Burbank potatoes. Before planting the ground was plowed and cultivated twice with a disk harrow. Four and one-half tons of seed were used, or at the rate of 0.81 of a ton, or 27 bushels, per acre. They were planted in rows 2½ feet apart and at intervals of 9 inches in the row. They were cultivated twice during the season and were not hoed.

The waterings were as follows:

Irrigation of potatoes on Sullivan Ranch.

Irrigation.	Time of beginning.	Duration of irrigation.	Water used.
		Hours.	*Acre-feet.*
First	June 4, 6 a.m.	36	3.14
Second	July 8, 6 a.m	12	4.03
Third	July 13, 6 a.m	12	3.51
Fourth	July 21, 6 a.m	12	2.09
Fifth	July 28, 6 a.m	12	3.59
Sixth	Aug. 4, 6 a.m	12	2.87
Seventh	Aug. 10, 6 a.m	12	2.80
Eighth	Aug. 14, 6 a.m	12	3.51
Ninth	Aug. 20, 6 a.m	12	3.63
Tenth	Aug. 27, 6 a.m	12	3.61
Eleventh	Sept. 1, 6 a.m	12	1.65
Twelfth	Sept. 9, 6 a.m	12	3.42
Thirteenth	Sept. 15, 6 a.m	12	3.51
Total			40.86

The depth of water applied during the season was 7.43 feet. The crop returns from the 5½ acres were 60 tons, or 10.9 tons per acre, equal to 363.3 bushels. At $13 per ton, which was the price realized, the value per acre for this crop is $141.70. All of the water used on the potatoes was measured, except the 3¼ acre-feet of the first irrigation, and this was estimated from Mr. Sullivan's notes.

ALFALFA.

Fifteen acres of this field were seeded in 1898, the remainder of the field, 85 acres, having been seeded in 1890 and used as a meadow since, two crops of hay being cut and the third pastured each year. The water is applied by running it in shallow furrows about 30 inches apart. These furrows run with the slope of the field, except when the incline is too steep. In such cases the furrows run diagonally across the slope, so as to reduce the velocity and give more time for the water to percolate to the roots of the plants.

The field was watered as follows:

Irrigation of alfalfa on Sullivan Ranch.

Irrigation.	Date.	Duration of irrigation.	Water used.
		Days. hrs.	*Acre-feet.*
First	Apr. 1, 6 a.m., to Apr. 14, 6 p.m	13 12	94.09
Second	May 12, 6 a.m., to May 23, 6 p.m	11 12	80.15
Third	May 28, 6 a.m., to June 9, 6 p.m	12 12	87.12
Fourth	June 15, 6 a.m., to June 25, 6 p.m	10 12	73.18
Fifth	July 6, 6 a.m., to July 17, 6 p.m	11 12	77.40
Sixth	July 27, 6 a.m., to Aug. 15, 6 p.m	19 12	100.13
Seventh	Aug. 27, 6 a.m., to Aug. 31, 6 p.m	4 12	27.93
Eighth	Sept. 8, 6 a.m., to Sept. 24, 6 p.m	16 12	114.96
Total			654.96

The depth of water applied was 6.55 feet. In addition to this, the alfalfa received any waste water escaping on the surface from the tracts of wheat and potatoes.

The returns from 100 acres of alfalfa were, first cutting, 300 tons; second cutting, 150 tons; a total of 450 tons. This hay is all fed on the farm and Mr. Sullivan values it at $6 per ton, or $2,700 for the crop. The returns from the pastures were $350. This gives a total for hay and pasture of $3,050, or at the rate of $30.50 per acre.

Mr. Sullivan is favorably situated for securing the best values for his crop, but if we estimate at $5 per ton, which was a common price last season, the value of the hay is $2,250. Adding the pasturage, $350, gives a total of $2,600, or at the rate of $26 per acre. Alfalfa is here the leading crop and is the reliance of the stockman in preparing his sheep and cattle for the market. The quality of the hay is such that range cattle and sheep are fattened on it, going to the market in prime condition for beef, without grain.

ORR DITCH.

Measurements were also taken of the water used on the lands under the Orr Ditch. This ditch heads 2 miles above Reno, and with the extensions covers some 6,000 acres, of which nearly one-half is irrigated. Two miles from the head the canal crosses a ravine in a flume, and at this point provision is made for letting out any surplus water which might tax the capacity of the ditch. Measurements of all the water passing to the irrigated lands were made in this flume below the wasteway. Beginning with May 3, daily gage readings were taken. This was continued till June 18, when a register was established (Pl. IX, fig. 2), after which a continuous record was kept until October 20, when, irrigation having practically ceased, the observations were discontinued. The volume in acre-feet passing each day is shown in the accompanying table and diagram.

Discharge of Orr Ditch, May 3 to October 20, 1900.

Day.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	132.50	113.08	121.87	104.08	....
2	....	138.45	106.85	119.47	21.47	....
3	98.18	141.42	99.83	115.63	83.58	....
4	101.55	138.45	107.72	102.76	37.48	....
5	72.99	144.40	112.20	11.29	38.51	....
6	78.74	132.50	113.14	83.14	75.13	29.10
7	....	149.97	110.11	111.90	95.87	87.27
8	....	138.45	123.43	112.33	99.85	70.26
9	104.13	135.49	131.80	120	115.34	55.77
10	104.13	130.91	156.96	118.98	122.86	90.64
11	104.13	126.93	160.22	97.81	125.03	73.66
12	104.13	121	160.73	31.07	124.22	60.50
13	104.13	117.02	159.10	135.48	125.04	55.12
14	104.13	113.06	149.19	135.31	122.72	43.24
15	99.97	107.10	122.96	129.99	108	43.24
16	99.97	113.65	94.52	137.70	100.84	42.25
17	99.97	120	120.30	137.27	98.56	42.25
18	99.97	130.53	122.98	119.43	89.77	42.25
19	114.65	141.42	124.23	33.34	99.94	33.99
20	129.52	138.64	122.36	125.67	115.34	12.16
21	129.52	140.23	121.85	126.54	112.25	....
22	129.52	136.56	124.51	127.07	104.47	....
23	131.50	124.96	130.54	138.75	109.14	....
24	127.93	120	125.88	137.63	92.77	....
25	127.93	119.67	124.43	119.79	97.99	....
26	127.93	117.03	125.90	29.42	94.06	....
27	129.52	121.04	124.61	131.91	109.14	....

Discharge of Orr Ditch, May 3 to October 20, 1900—Continued.

Day.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
28	129.92	119.85	109.89	134.84	95.19	
29	130.51	119.05	40.84	135.72	126.35	
30	128.38	120.28	127.23	135.48		
31	126.15		122	136.66		
Total	3,039.05	3,850.56	3,789.39	3,454.25	2,844.99	781.72

The record shows a total discharge of 17,759.96 acre-feet. This does not include the water used between April 10, when the ditch was first put in operation, and May 3, when the record began. The superintendent reports that the daily use of water for this period was about the same as during the month of May. The total measured discharge in the twenty-seven days of May for which observations were made is 3,039 acre-feet, an average of 112.55 acre-feet per day. Multiplying this by 23, the number of days for which no measurements were taken, the product is 2,588.7 acre-feet, which, added to the 17,759.96 acre-feet measured, makes a total for the season of 20,348.66 acre-feet. The following table shows the duty under the ditch:

Duty of water under Orr Ditch, 1900.

	April.	May.	June.	July.	August.	September.	October.	Total.
Area irrigated, acres	2,877	2,877	2,877	2,877	2,877	2,877	2,877	2,877
Water used, acre-feet	2,588.70	3,039.05	3,850.56	3,789.39	3,454.25	2,844.99	781.72	20,348.66
Depth of water used in irrigation, foot	.90	1.06	1.34	1.32	1.20	.99	.27	7.08
Rainfall, foot	.15	.03	.09	.02	.02	.06	.04	.41
Total depth of water received by land, feet	1.05	1.09	1.43	1.34	1.22	1.05	.31	7.49

YIELD AND VALUE OF CROPS.

Below are given the yields and values of crops under the Orr Ditch, as reported by individual irrigators:

Oats.

Name of irrigator.	Area.	Number of irrigations.	Yield.	Value of crop.
	Acres.		*Tons.*	
J. J. Becker	30	3	10	$250
J. Curnow	40	10	8	200
B. D. Dunning	5	8	3	75
W. Frazer	30	6	27	675
J. H. Gault	10	6	5	125
T. E. Haydon	80	20	24	600
J. Pollock	30	6	15	375
M. Shields	3	6	2	50
T. Tinkham	5	7	3	72
E. Wills	6	7	5	125
Total	239		102	2,547

Wheat.

Name of irrigator.	Area.	Number of irrigations.	Yield.	Value of crop.
	Acres.		*Tons.*	
W. R. Bradley	4	14	(1)	....
G. A. Cole	4	12	4	$76.00
J. Curnow	12	10	5	95.00
C. O. Dixon	4	7	5	95.00
B. D. Dunning	30	8	7	140.00
J. N. Evans	20	6	20	400.00
W. Frazer	5	6	4	76.00
J. Gault	40	6	30	570.00
J. H. Gault	15	8	8½	161.50
M. Gulling	25	4	22	400.00
T. E. Haydon	60	20	17	328.00
E. H. Mathews	25	6	25	500.00
J. Pollock	50	6	45	832.50
M. Shields	40	6	35	700.00
J. W. Spurling	5	8	5	95.00
J. Sullivan	10	6	10	190.00
T. Tinkham	15	7	8	152.00
Do	14	8	10	200.00
W. P. Van Meter	40	15	15	285.00
Total	418	....	275½	5,294.00

[1] Cut for hay.

Potatoes.

Name of irrigator.	Area.	Number of irrigations.	Yield.	Value of crop.
	Acres.		*Tons.*	
W. R. Bradley	½	14	....	....
G. A. Cole	1	15	8¼	$107.25
J. N. Evans	1¼	9	10	150.00
E. H. Matthews	3	12	25	350.00
J. Pollock	15	10	120	1,560.00
M. Shields	2	12	20	260.00
J. W. Spurling	1	15	4	52.00
J. Sullivan	5½	12	60	780.00
C. R. Upson	1	....	3	....
Total	30¼	....	250¼	3,259.25

Alfalfa.

Name of irrigator.	Area.	Number of irrigations.	Number of cuttings.	Hay.	Value of hay.	Value of pasture.
	Acres			*Tons.*		
H. Anderson	40	6	2	120	$660.00	$75.00
J. J. Becker	120	7	2	250	1,250.00	240.00
W. R. Bradley	15	22	2	32	160.00	20.00
G. A. Cole	12	15	3	65	357.50	34.50
J. Curnow	20	20	1	80	400.00	250.00
C. O. Dixon	75	10	2	150	825.00	150.00
B. D. Dunning	75	15	2	275	1,375.00	150.00
J. N. Evans	18	10	2	75	450.00	50.00
W. Frazer	90	10	2	175	962.50	300.00
J. Gault	50	8	2	200	1,100.00	170.00
J. H. Gault	25	10	2	100	550.00	120.00
J. Grose	30	12	2	75	375.00	....
M. Gulling	80	4	2	150	750.00	171.00
T. E. Haydon	70	20	3	350	1,575.00	105.00
G. B. Hinkle	16	15	2	40	240.00	16.00
P. J. Kelley	48	10	2	120	600.00	100.00
E. H. Mathews	35	12	2	75	375.00	120.00
J. Pollock	180	10	2	550	3,025.00	250.00
M. Shields	80	10	2	175	1,050.00	150.00
J. W. Spurling	52	12	2	80	440.00	....
J. Sullivan	175	8	2	600	3,600.00	500.00
T. Tinkham	50	8	2	120	600.00	150.00
Do	35	12	2	100	500.00	50.00
Do	75	11	2	150	750.00	100.00
T. Tomannchel	40	8	2	100	500.00	80.00
C. R. Upson	18	10	2	40	240.00	20.00
W. P. Van Meter	70	10	2	120	540.00	....
E. Wills	44	10	2	140	700.00	100.00
Total	1,638	....	....	4,507	23,950.00	3,471.50

FIG. 1.—MODULE THROUGH WHICH WATER IS MEASURED TO EXTENSION OF ORR DITCH.

FIG. 2.—MEASURING DEVICE ON LATERAL FROM ORR DITCH.

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In addition to the above crops there were 522 acres in pasture, 20 acres in orchard and garden, and 10¼ acres of yards and lawns, a total of 2,877½ acres. Estimating the 522 acres of irrigated pasture at $6 per acre, its value is $3,132. The orchard products reported are 3,120 boxes, mostly apples. At 75 cents per box these amount to $2,340. The small fruits and vegetables reported amount to $100. Adding all the values reported:

Oats	$2,547.00
Wheat	5,294.00
Potatoes	3,259.25
Alfalfa	27,421.50
Irrigated pasture	3,132.00
Orchard	2,340.00
Small fruits and garden	100.00
The total returns are	44,093.75

Dividing this total by 2,877½, the whole number of acres irrigated, the quotient is the average return per acre, $15.32. The wheat and oat crops for this season were much below the ordinary. The potato crop was good and the alfalfa a fair average. Comparing the total value of all the crops with the number of acre-feet of water used, the return per acre-foot is $2.16.

The stock of the Orr Ditch Company is divided into 248 shares, each of which entitles its owner to 10 inches of water. All the stock except 68 shares is owned by the parties who use the water. The number of stock owners is 62, and their holdings range from one-fourth share up to 26½ shares. The stock not owned by the irrigators has a rental value of $25 per share, or $2.50 per inch.

This canal was built in 1862, and was originally about 12 miles long. Later it was extended and enlarged by the Orr Extension Company, and was still further extended by the Spanish Springs Valley Ditch Company. The total length is about 22 miles. The Extension Company and the Spanish Springs Company own 133 of the 248 shares in the original ditch. Plate X, fig. 1, shows the module through which the water is measured for the two extensions.

The expense of the maintenance of the original Orr Ditch was for 1900 $1,210.87. This was borne by the stockholders of the three companies. The cost of operating the Orr Extension was $300 more. This was met by the two latter companies. An additional expense of $300 was incurred by the Spanish Springs Company in operating the third section. This was borne by the Spanish Springs Company alone.

Reviewing the measurements made at the different stations, we have depth applied as follows:

	Feet.
Experiment farm:	
Wheat	8.26
Potatoes	8.16
Experiment plats, 15 acres	4.53

	Feet.
Sullivan's ranch:	
Wheat	14.24
Potatoes	7.43
Alfalfa	6.54
Orr Ditch:	
Average depth for all the lands watered	7.08

The volume, measured at the flume, delivered during the past season by the Orr Ditch was 20,348 acre-feet. Dividing this by 2,363, the number of inches to which the shareholders below the flume are entitled, gives 8.6 acre-feet as the equivalent of 1 inch. The average water user in the Truckee Valley expects to use this volume on an acre, and feels that there is something wrong if he does not get it.

On the higher lands, where the slope is sufficient to carry off the surplus, or where the subsoil is porous and permits the escape of the water into the gravel below, the effects of such excessive watering, though not immediately apparent, are none the less sure. By such copious irrigation the soluble soil ingredients, those which are available for plant food, are leached out and carried away with the escaping water to the lower-lying lands, to reappear there as hurtful alkalis, destructive to vegetation. The soil of the uplands is being impoverished, while the lower lands are being converted into swamps. A good deal of the best land in the lower part of the valley has already become so water-logged and charged with alkali that it can not be cultivated and now produces little except coarse swamp grasses.

Summarizing the yields and their values we have:

Yields and value of crops, 1900.

Crop.	Yield per acre.		Value per acre.
	Tons.	Bushels.	
Experiment farm:			
Wheat	0.84	27.97	$16.78
Potatoes	11.48	382.7	172.20
Sullivan's ranch:			
Wheat	1.46	48.75	29.25
Potatoes	10.90	363.3	141.70
Alfalfa	4.50	....	[1] 30.50
Orr Ditch:			
Oats	.427	26.68	10.65
Wheat	.659	21.96	12.66
Potatoes	8.27	276	107.74
Alfalfa	2.75	....	[1] 16.74
All crops	....	....	15.32

[1] The value per acre of the alfalfa includes the pasturage of the third crop. The yields recorded are much less than were formerly obtained from these lands, and it is believed by good farmers that this falling off is largely due to soil deterioration from excessive watering.

UTAH.

WATER ADMINISTRATION IN UTAH.

By Special Agent R. C. Gemmell,
State Engineer of Utah.

In his report of the investigations made on Big Cottonwood Creek in 1899[1] the writer gave a brief history of the adjudication of the waters of Big Cottonwood Creek by arbitration, as well as a description of the manner in which water rights were obtained and held and the water divided and distributed. At some risk of repetition, these subjects will again be discussed in this report.

Two very important questions closely associated with irrigation in Utah will soon force themselves upon the attention of the people of the State in such a manner as will admit of no further evasion of the issue. The future growth and prosperity of the State depend largely upon how these questions are decided. They are: (1) How shall the water rights on the various streams be adjudicated, and (2) how shall the water be divided and distributed?

TITLES TO WATER.

Water is personal property in Utah, and rights are sold, exchanged, and leased with little regard for legal formalities, and often without making any official record of the transactions. When a farmer finds that his water right furnishes more water than he needs, he buys another piece of land and transfers a part of his water right to it, or he rents a part of it by the year to some neighbor who can use it, or perhaps he sells a part or all of it outright. A ditch company discovers that it has more water than the members of the company need and at once proceeds to rent or sell a part of its rights to some other ditch company. And yet only a very small percentage of the irrigators of Utah have definite, undisputed, legally defined titles to water. The seller does not know what he is selling, nor the buyer what he is buying. The water transferred is supposed to irrigate a certain number of acres. It may irrigate more or less, depending upon the available supply in the streams and upon how the water master divides it. No attempt is ever made to measure out any certain quantity of water.

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

There is no method by which the owner of a tract of land can acquire directly from the public a right to the water which reclaims that land, but it is necessary in this State to go into the courts in order to acquire titles to water. This is not only a tedious and expensive method, but it is also a very unsatisfactory one. The trial of one case sometimes costs as much as would be required to conduct a properly organized State engineer's office and board of control for an entire year, and a case that could be adjudicated by a board of control in a few weeks may require several years to be decided by the courts.

ADJUDICATIONS BY THE COURTS.

In nearly every part of Utah the rights on some of the streams have been or are now being adjudicated by the courts, and much time and money is being spent in litigation—uselessly spent, because few decrees of court in water cases are satisfactory to anyone. This is mainly because of the fact that the courts usually have no series of stream measurements and no reliable information either as to the acreage irrigated or the duty of water upon which to base a decree. The case is tried in a court room 15 or 20 miles distant from the stream and land in question; masses of unreliable, inaccurate, and contradictory testimony are elicited and recorded, and then the result, almost inevitably, is a decree unsatisfactory to the majority of the litigants. The writer himself knows of decrees awarding five or six times the amount of water flowing in the streams. Already thousands of dollars have been spent in lawsuits on nearly every large stream in the State, from which the water users have derived no material benefit.

ADJUDICATIONS OUTSIDE OF THE COURTS.

On some streams the rights have been adjudicated by water commissioners under the act of 1880 and by boards of arbitration, the members of which were first chosen by the people interested and then appointed by the courts. Such an adjudication is usually more satisfactory to the majority of the water users on a stream than would be a decree of the court, because the case is investigated and the testimony taken right on the ground. But, judging from the cases that have come under the writer's notice, the commissioners or arbitrators have always failed to secure sufficiently accurate information upon which to base their findings, and they do not provide for a proper and accurate administration of their decisions. They do not, for one thing, even obtain accurate data as to the acreage irrigated. The information upon which the findings are based being inaccurate, the adjudications are soon found to be unjust and unsatisfactory.

In the report for 1899 on Big Cottonwood Creek, one of the streams adjudicated by a board of arbitrators, the following statement was made: "The whole matter of division of the water seems to be in a

very unsatisfactory condition. In all probability the trouble will culminate in a lawsuit involving all of the rights on the creek." This prophecy was fulfilled during the summer of 1900 by the owners of the Big Ditch bringing suit against all of the other appropriators on the creek.

The law should provide for a board of control to adjudicate all of the rights on all of the streams of the State. The original appropriators of water in Utah are passing away. As their testimony is of the greatest value in obtaining correct adjudications of streams, it should be placed upon record at the earliest possible time. The sooner this is done the better; the longer it is postponed the more difficult and costly it will be to obtain the information necessary for equitable adjudications. If the water laws of Utah are allowed to remain in their present shape, it is safe to say that many times the amount of money required to properly adjudicate every water right in the State will be spent in litigation during the next twenty-five years.

RECORDS OF WATER RIGHTS.

At the present time the offices of the various county recorders are the proper places of record for water rights. As a matter of fact, however, probably not one-half of the water rights in the State are so recorded, and in some localities practically none of them are recorded. The records used in making distribution of the water are those kept by the water masters, and, in fact, they are the records upon which the ownership of water is mainly based. As it is now, it is extremely doubtful if the water rights of a single stream in the State of Utah are so recorded as to show to whom the water really belongs. As a general rule, the records are not only incomplete, but the claims to water are so indefinite in description that their true meaning and value can not well be ascertained. Appropriations of water, claims to water, adjudications of boards of water commissioners and boards of arbitration, and transfers of water rights are supposed to be carefully recorded in the offices of the county recorders, but it is unsafe to assume that they are so recorded. To endeavor to accurately determine the rights to the waters of any given stream from a study of the records is disheartening work; in fact, it is practically impossible to do so. One may meet with reasonable success in the recorder's office, only to learn later that the rights there recorded have been materially changed by a decree of court, which is recorded in the clerk's office. In neither office are the records systematically kept, so as to show all of the rights on each stream in a convenient and intelligible manner. Not only should there be one office of record for all water rights in the State, and water users be compelled to record their rights, but the rights on each stream should be recorded separately and the descriptions of them should be uniform and definite.

DIVISION AND DISTRIBUTION OF WATER.

The waters of none of the streams of Utah are accurately divided. This is a very strong statement—none the less a true one. Boards of water commissioners, boards of arbitration, and courts have rendered decisions regarding the waters of various streams in all parts of the State, granting certain water rights to each ditch, and yet it is safe to say that not a single decision of arbitrators or decree of court is being properly carried out. There is no State officer whose duty it is to see that the water is divided in accordance with the decisions and decrees, but the matter is usually left to the farmers themselves. The latter are generally honest in their efforts to divide the water, but their methods are very crude and they simply will not go to the trouble and expense of doing it accurately. The law should provide for an officer in each district, acting under the orders of the board of control, whose duty it would be to divide the waters of his district in strict accordance with the established priority of rights.

The following table shows the quantities of water actually diverted by eight of the canals and ditches on Big Cottonwood Creek during the irrigation season of 1900, together with the quantities that would have been diverted if the water had been divided in accordance with the allotments of the board of arbitrators. During the season of 1900 there was an unusually small amount of water in the creek.

Quantities of water diverted by canals from Big Cottonwood Creek during the irrigating season of 1900, and the quantities that would have been diverted if the water had been divided in accordance with the allotments of the board of arbitrators.

Name of canal.	April, May, and June.		July, August, and September.	
	Allotted.	Diverted.	Allotted.	Diverted.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
Butler Ditch	165.0420	571.4372	22.3348	84.0973
Brown & Sanford Ditch	1,485.3781	3,429.6142	234.5156	762.3450
Upper Canal	3,465.8824	4,819.6313	1,139.0756	1,194.2133
Tanner Ditch	4,159.0588	3,548.2275	1,440.5956	1,661.9259
Green Ditch	1,155.2941	2,133.5168	424.3615	729.6831
Farr & Harper Ditch	198.0504	387.7081	67.0045	44.8149
Lower Canal	1,848.4705	1,117.2876	681.2119	509.1563
Big Ditch	6,469.6470	2,939.4006	2,378.6579	1,401.4916
Total	18,946.8233	18,946.8233	6,387.7574	6,387.7574

The canals are given in the table in their order, coming downstream. The table shows that throughout the season the upper canals drew more water than they were entitled to, while at no time during the season did the lower canals get their allotted share of the water. There should be some officer to see that the upper canals do not take advantage of their position to draw more than their share of the water while those below suffer.

PERMITS TO APPROPRIATE WATER.

In the future no person or corporation should be allowed to appropriate any of the waters of the State, for any purpose whatever,

without first obtaining a permit to do so from the State engineer. This provision alone would put a stop to much of the litigation that is now being carried on in nearly every part of the State. As the matter stands now, the ordinary flow of a stream may be entirely appropriated and used, and yet there is no way of preventing persons from going higher up on the stream, building ditches, and diverting a portion of its waters to their own uses. Such persons may, at first, state that they only intend to divert the surplus during high water, but gradually they will encroach upon the ordinary flow, and, unless interfered with, will eventually acquire rights to a portion of it. In such cases the only recourse of prior appropriators in the State of Utah to prevent their water from being stolen is to go to the expense of tearing out the dams and headgates of the new ditches and of bringing actions in some court of law.

It is not meant that surplus waters should not be appropriated and diverted for beneficial uses; on the contrary, wherever practicable, all surplus or high water should be diverted and used. In many parts of Utah this is or can be done, and early maturing crops, such as wheat, can be irrigated during high water and made to yield good returns. But users of high water should not be allowed to interfere with appropriators owning primary rights. In cases where there may be no unappropriated water, or where the proposed use of water might prove detrimental to private or public interests, the State engineer should refuse to issue permits. This would relieve the people of one cause of many quarrels and expensive lawsuits.

DUTIES OF THE STATE ENGINEER.

In order to make the State engineer's office what it should be, and remedy the difficulties described, changes in the water laws of Utah should be made as follows:

(1) The office of the State engineer should be made the office of record of all claims to water, and the law should compel all owners of existing rights to record their claims.

(2) All county records of claims to appropriations of water should be transferred to the office of the State engineer, who should classify and file the same.

(3) All persons or corporations desiring to appropriate water should be required to secure a permit to do so from the State engineer before beginning the construction of any ditch or canal.

(4) The State should be divided into four water divisions, provision being made for the appointment of one superintendent for each division, who should report to the State engineer. Division superintendents should have authority to make such regulations as will secure the proper distribution of the water, reserving the right of appeal from said regulations to the State engineer.

(5) The State engineer and division superintendents should be con-

stituted a board of control, to adjudicate the rights to all the public waters of the State, reserving the right of appeal from the decisions of said board to the courts.

(6) The State engineer should be authorized and directed to make an examination of any stream to be so adjudicated, such examination to include measurements of discharge of streams, surveys of canals or ditches diverting water therefrom, measurements of the lands irrigated by the said canals or ditches, and the securing of any other information that would be of assistance in the adjudication.

(7) The board of control should be authorized and directed to divide each water division into water districts, said water districts to be so arranged as to secure the best protection to the claimants of water and the most economical supervision on the part of the State. For each water district thus created there should be appointed one water commissioner, whose duty it would be to divide the water in the natural stream or streams of his district among the several ditches taking water therefrom according to the rights of each as determined by the adjudications of the board of control.

(8) All appropriations of water for reservoir purposes should be filed in the office of the State engineer, who should keep a record of same separate and apart from the record of rights to the direct use of water from the natural flow of streams. Every water-right filing for reservoir purposes should state the purpose, give the capacity of the proposed reservoir, and designate the months of the year during which the water will be stored. As between appropriations for storage, the first in time should be first in right; but storage rights should be inferior to rights to water for direct application to beneficial uses.

The first users of water from a storage reservoir should have preference over others; in other words, the oldest customers should have the first rights to the use of the water, provided they promptly pay the agreed rates charged for it. In case of disagreement between customers and reservoir owners as to said rates the matter should be submitted to three arbitrators, one chosen by the water users, another by the reservoir owners, and the third by the State engineer. The rate to be charged for stored water should be determined by the arbitrators on the basis of the cost of constructing and maintaining the reservoir and canals; in other words, the rate should be so fixed as to insure to the reservoir owners a fair interest on the money invested in the works.

Where stored water is mingled with the natural flow of streams or with the water of another storage reservoir, provision should be made for reclaiming it without interfering with the rights of others. The owners of the reclaimed water should be compelled to construct and maintain, under the direction of the State engineer, accurate means of measuring the water, both at the point of turning in and the point of reclamation. Before the stored water is turned into a natural stream the water commissioner should be notified, and, under general

instructions from the State engineer, said water commissioner should measure the volume turned in and supervise its distribution to those entitled to its use, giving them the amount turned in, less the loss by seepage and evaporation in transit.

The writer is well aware that numerous objections to this plan of controlling the waters of the State will be conjured up in the minds of some, and that it will be claimed that too much power is given to one man, viz, the State engineer. A discussion of what these objections might be, and of the arguments which could be used to refute them, will not be entered into here. It is sufficient to say that all objections can be refuted, and that, too, in a few sentences. The plan here recommended has been in operation in Wyoming for about ten years. Out of 3,887 water rights that have been adjudicated by the board of control only one case has been appealed to the courts. No better practical proof of the utility and success of the plan could be given.

DUTY OF WATER ON BIG COTTONWOOD CREEK, 1900.

By Special Agent R. C. GEMMELL, *State Engineer of Utah.*

INTRODUCTION.

The observations made on Big Cottonwood Creek canals in 1899 were continued in 1900. The canals and ditches were cleaned out early in April, the work being completed in most cases by April 10. Measurements were begun in each canal as soon as water began to be used for irrigation. As there was quite a heavy rainfall on September 24, no water was used for irrigation after September 23, although the canals still continued to divert some water from the creek for domestic purposes.

Except in the case of the Brown & Sanford Ditch, the water was measured over Cippoletti trapezoidal weirs (Pl. XI). The weir in the Brown & Sanford Ditch was cut out by the owners of that ditch on April 16, and measurements were not again begun until May 1. On and after that date the measurements were made with a current meter in a dividing box, located at the junction of the right and left forks of the ditch at about 2,400 feet below the point of diversion. The owners of the Tanner Ditch would not allow a weir or other measuring device to be put in where all of the water they diverted could be measured. During a small part of the season they ran a little water from the creek through a small branch, turning it into their ditch at a point about 50 yards below the weir, and an estimated allowance was made for it. It is impossible to determine how much of the water measured in the Walker Ditch was used for irrigating purposes. The weir in the Hill Ditch was torn out by the farmers a few days after measurements were begun. Therefore, no attempt has been made to calculate the duty of water under the Walker or Hill ditches.

The heads on the weirs were measured twice a day with a hook gage.

The depths of water in the dividing box on the Brown & Sanford Ditch were also measured twice a day; gagings were made with a current meter, and a curve of discharge was constructed in the usual manner. It is believed that these measurements give the discharges of the various canals and ditches with a considerable degree of accuracy, as care was taken to keep the weirs in good condition.

An attempt was made to keep a record of the evaporation. The evaporation tank was set in accordance with instructions, but it seemed to be impossible for the observer to understand his duties. At all events, the results were so unsatisfactory that the records were considered worthless. At one time a cow obtained access to the tank and drank some of the water, and this may have occurred more than once. Arrangements will be made hereafter so that these accidents will not happen and the records will be properly kept. The records of the precipitation were also unsatisfactory, and those of the Weather Bureau at Salt Lake City have been used instead.

BUTLER DITCH.

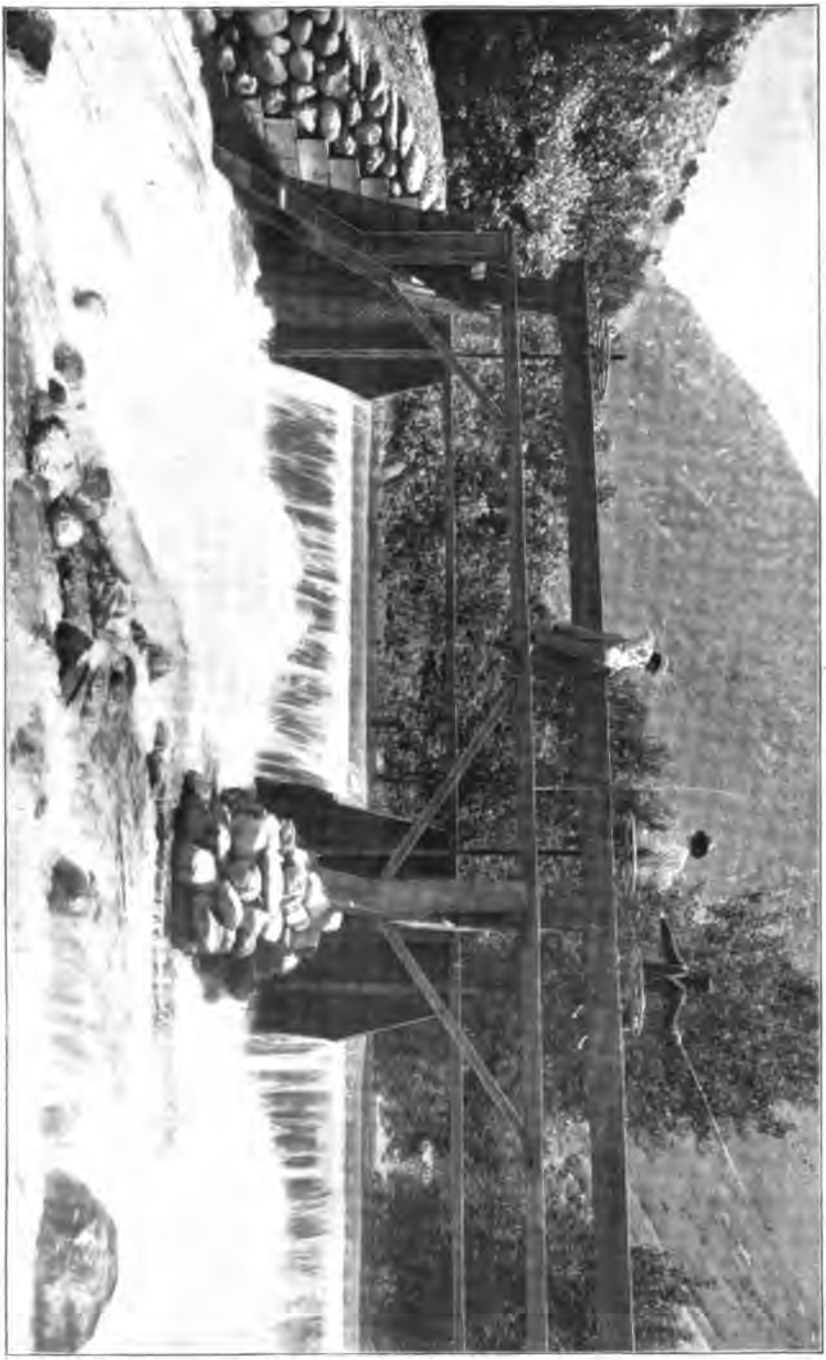
The area irrigated by this ditch was 126.5 acres, all of which is sandy, gravelly bench land, requiring much water. About 655.5 acre-feet of water was used, and if it had all been applied on the land it would have given a depth of 5.18 feet. The water was measured at about 1 mile below the head of the ditch, and there is considerable loss by seepage and evaporation between that point and the irrigated land. The area irrigated per cubic foot per second was 60.1 acres. In addition to the irrigating water, this land received during the irrigating season about 0.49 foot of rainfall. The irrigating season began April 20 and closed September 23.

The principal crops raised were alfalfa and potatoes. The yield of potatoes was good, but the alfalfa made only about one-half of a good crop, on account of damage done to the second and third cuttings by grasshoppers. If it had not been for the grasshoppers it is thought a good crop of alfalfa would have been raised, and, therefore, under the conditions and methods prevailing on this ditch the probability is that a duty of 60 acres per cubic foot per second is about right for this porous bench land.

The following tables contain the data regarding the water used in irrigating lands under this ditch:

Water used in irrigating lands under Butler Ditch, 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	2.1818	13.0909	2.1818	0.7934	0.7934
2	....	2.3802	13.2892	1.9835	.7934	.7934
3	....	2.5785	13.6859	1.9835	.7934	.9917
4	....	2.4793	13.2892	1.5868	.9917	1.1901
5	....	2.9752	13.2892	1.2892	.9917	1.1901
6	....	4.1653	12.2975	1.0908	1.1901	1.3884
7	....	4.1653	11.9008	.9917	.9917	1.5868
8	....	4.1653	10.9091	.9917	.9917	1.6859



WEIR ON BIG COTTONWOOD CREEK.

FIG. 1.—BIG COTTONWOOD CREEK, LOOKING WEST FROM MOUTH OF CANYON.

FIG. 2.—LAND UNDER TANNER AND BROWN & SANFORD DITCHES.

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Water used in irrigating lands under Butler Ditch, 1900—Continued.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
9		6.3471	10.9091	0.7934	0.9917	1.7851
10		11.3057	11.3057	.8925	.8925	1.7851
11		13.4876	11.1074	.9917	.9917	1.9835
12		12.6942	10.6115	.5950	.9917	1.9835
13		7.1405	10.3140	.7934	.9917	1.7851
14		7.8346	10.1157	.6941	1.1901	1.7851
15		7.7355	10.0165	.5950	1.1901	1.5868
16		10.9091	9.7190	.4958	1.1901	1.5868
17		11.9008	9.7190	.4958	.9917	1.6859
18		12.0992	9.5207	.7934	.9917	1.5868
19		11.9008	5.5537	.5050	.9917	1.5868
20	1.9835	11.9008	5.4545	.4958	.9917	1.3884
21	2.5785	11.9008	6.1488	.4958	1.0908	1.4875
22	2.5785	12.6942	6.9421	.3967		1.2892
23	2.3802	12.6942	5.9504	.8925		1.1901
24	2.7769	12.4959	4.5619	.9917		
25	2.3802	11.9008	3.3719	.8925		
26	2.2809	12.0992	2.7769	.9917		
27	2.3802	12.4959	2.3802	.9917		
28	2.5785	12.6942	2.7769	.8925		
29	2.5785	12.2975	2.9752	.7934		
30	2.7769	12.8926	2.3802	.6941		
31		13.2892		.5950		
Total	27.2728	287.8013	256.3631	28.9575	21.0243	34.1155

Duty of water under Butler Ditch, 1900.

Month.	Area.[1]	Water used.		Area, per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	126.5	27.2728	0.21	
May	126.5	287.8013	2.27	
June	126.5	256.3631	2.03	
July	126.5	28.9575	.23	
August	126.5	21.0243	.17	
September	126.5	34.1155	.27	
Total irrigation		655.5345	5.18	60.10
Rainfall			.49	
Total water received			5.67	

[1] It is impossible to tell just how much of the land under the ditch is irrigated each month. For the purpose of computing the depth of water used, the whole area is assumed to have been irrigated each month.

[2] Continuous flow for 157 days.

BROWN & SANFORD DITCH.

The area irrigated by this ditch was 1,028.5 acres, all of which is sandy, gravelly bench land, requiring much water. About 4,192 acre-feet of water was diverted, and if it had all been applied on the land it would have given a depth of 4.07 feet. The water was measured about 2,400 feet below the head of the ditch, and there is considerable loss by seepage and evaporation between that point and the irrigated land. The area irrigated per cubic foot per second was 80.78 acres. In addition to the irrigating water, this land received during the irrigating season about 0.49 foot of rainfall. The irrigating season began April 11 and closed September 23.

Grain and fruit made about two-thirds of a crop; alfalfa and potatoes

about one-half of a crop. The second and third cuttings of alfalfa were badly damaged by grasshoppers. Under the conditions and methods prevailing on this ditch, it would seem that a duty of 80 acres per cubic foot per second is too high for this porous bench land.

The following tables contain the data regarding the water used in irrigating lands under this ditch:

Water used in irrigating lands under Brown & Sanford Ditch, 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		13.0909	80.8263	18.2479	6.5454	12.2975
2		20.5288	74.3801	15.8677	6.9421	12.7933
3		34.8090	75.4710	13.7850	6.9421	12.4959
4		34.3140	64.5619	10.4131	6.6454	13.2892
5		34.3140	65.1569	8.5289	6.1488	14.0826
6		36.4958	63.8677	9.1240	6.3471	15.2727
7		39.2726	63.8677	8.7272	5.7521	17.3553
8		53.7520	63.2727	8.3306	5.7521	17.8512
9		54.0495	62.6777	7.3388	5.3554	18.0495
10		55.1405	60.3966	6.1488	5.5537	18.2479
11	12.8926	55.9339	58.7107	5.7521	5.5537	18.0495
12	11.9008	55.7355	58.4131	4.1653	5.3554	17.8512
13	12.3966	55.6363	58.4131	3.5702	4.9587	17.6528
14	12.8926	55.5372	57.8181	2.9752	4.7604	17.6528
15	14.2809	55.3388	57.8181	2.4793	5.1570	17.6528
16	14.2809	55.2396	57.1239	2.0826	4.7604	17.8512
17	14.0826	55.1405	56.4296	5.3554	4.5619	8.5289
18	14 0826	54.9421	52.8594	5.1570	4.5619	17.0578
19	13.8842	54.7438	35.9999	4.7604	4.3636	16.2644
20	13.8842	54.5454	35.4048	4.3636	4.5619	16.2644
21	13.8842	54.3471	34.8098	4.7604	4.1653	15.6094
22	13.6859	68.0330	34.3140	4.7604	4.3636	15.3718
23	13.6859	77.0577	30.7437	6.3471	5.9504	15.0743
24	13.6859	76.2643	24.7933	6.1488	6.5454	
25	13.4876	74.2809	18.7437	5.7521	8.1322	
26	13.4876	73.7851	13.9833	5.7521	8.9256	
27	13.4876	73.9834	12.7933	5.9504	8.7272	
28	13.2892	80.8263	13.2892	5.3554	8.5289	
29	13.2892	77.9504	14.7767	5.5537	8.1322	
30	13.2892	78.9421	13.7850	4.9587	8.5289	
31		80.2313		4.3636	10.3140	
Total	269.8503	1,744.2626	1,415.5013	206.8758	192.7928	362.6764

Duty of water under Brown & Sanford Ditch, 1900.

Month.	Area [1]	Water used.		Area per cubic foot per second. [2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	1,028.5	269.8503	0.26	
May	1,028.5	1,744.2626	1.70	
June	1,028.5	1,415.5013	1.38	
July	1,028.5	206.8758	.20	
August	1,028.5	192.7928	.19	
September	1,028.5	362.6764	.35	
Total irrigation		4,191.9592	4.08	80.78
Rainfall			.49	
Total water received			4.57	

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 166 days.

UPPER CANAL.

The area irrigated by this canal was 1,533.9 acres, of which about 300 acres is gravelly bench land; about 800 acres is a light, clayey bench land, not requiring quite so much water as the gravelly bench land; about 90 acres is loamy bottom land, requiring still less water, and the remainder is sandy bench land. About 6,013.9 acre-feet of water was diverted, and if it had all been applied on the land it would have given a depth of 3.92 feet. The water was measured at about 600 feet below the head of the canal, and there is considerable loss by seepage and evaporation between that point and the irrigated land. The area irrigated per cubic foot per second was 83.98 acres. In addition to the irrigating water this land received during the irrigating season about 0.49 foot of rainfall. The irrigating season began on April 11 and closed September 23.

Grain made a fair crop, being about five-sixths of what is called a good crop; alfalfa made about three-fourths of a crop; fruit about one-half of a crop; potatoes about two-fifths of a crop; vegetables about one-fifth of a crop. Under the conditions and methods prevailing on this canal it would seem that a duty of 84 acres per cubic foot per second is too high.

The following tables contain the data regarding the water used in irrigating lands under this canal:

Water used in irrigating lands under Upper Canal, 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		43.1404	97.9834	37.4875	16.1652	12.8926
2		40.6611	98.9752	37.1899	15.8677	12.1983
3		38.0826	99.9669	24.3966	15.3718	12.1983
4		40.2644	100.3636	22.4132	14.8760	12.1983
5		54.3471	98.9752	22.4132	14.6776	12.4959
6		56.1157	97.5867	21.8182	13.8842	12.6942
7		64.2644	84.8925	21.2231	13.3883	12.1983
8		64.6611	83.9008	20.7272	12.1983	11.7025
9		76.3636	83.9008	20.4297	12.1983	11.7025
10		82.9090	83.1074	19.6363	12.1983	11.3057
11	29.3553	80.7272	80.7272	19.3387	11.9008	11.0082
12	29.6528	85.1900	79.4379	20.4297	12.1983	10.8098
13	32.2313	68.4297	80.3305	16.4628	11.7025	10.6115
14	30.9421	60.8925	79.4379	15.8677	11.7025	10.1157
15	29.6528	58.9091	78.1487	15.3718	11.5041	9.9174
16	33.5206	58.9091	75.1735	15.0743	11.3057	10.1157
17	27.4709	59.3058	72.5950	14.3800	11.5041	10.1157
18	27.1734	56.6280	73.3884	14.6776	11.1074	10.1157
19	29.6528	55.4379	50.0825	13.8842	11.1074	9.7190
20	32.9256	51.8677	49.3884	14.3800	11.3057	9.3223
21	36.4958	56.2313	48.5950	15.0743	11.1074	9.1240
22	37.4875	70.4132	49.3884	14.8760	10.8098	9.3223
23	39.2726	72.0991	44.6281	14.8760	10.3140	8.6280
24	36.4958	73.3884	41.0578	14.8760	10.6115	
25	31.9339	72.9917	39.9668	14.0826	10.8098	
26	34.5123	73.3884	38.5783	14.3800	11.3057	
27	35.1074	76.4627	34.5123	14.3800	11.1074	
28	39.6694	94.8099	35.3057	13.1900	10.8098	
29	45.6198	97.9908	36.0991	13.1900	11.3057	
30	43.1404	98.9752	36.8925	12.8926	11.1074	
31		98.9752		16.8595	12.0000	
Total	682.3125	2,083.9323	2,053.3865	566.2787	377.4527	250.5119

Duty of water under Upper Canal, 1900.

Month.	Area.[1]	Water used.		Area per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	1,533.9	682.3125	0.44	
May	1,533.9	2,083.9323	1.36	
June	1,533.9	2,053.3865	1.34	
July	1,533.9	566.2787	.37	
August	1,533.9	377.4527	.25	
September	1,533.9	250.5119	.16	
Total irrigation		6,013.8746	3.92	83.98
Rainfall			.49	
Total water received			4.41	

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 166 days.

TANNER DITCH.

The area irrigated by this ditch was 1,576.8 acres, of which about 700 acres is gravelly bench land, about 300 acres is sandy, loamy bottom land, and the remainder is a light clayey bench land. About 5,704 acre-feet of water was diverted from the creek and from springs, and if it had all been applied on the land it would have given a depth of 3.62 feet. The water was measured about 200 feet below the head of the ditch, and there is considerable loss by seepage and evaporation between that point and the irrigated land. The area irrigated per cubic foot per second was 91.02 acres. In addition to the irrigating water the land received during the irrigating season about 0.49 foot of rainfall. The irrigating season began April 11 and closed September 23.

Grain made a fair crop, being about three-fourths of what is called a good crop; fruit made about one-half of a crop; alfalfa about two-thirds of a crop; potatoes about three-fifths of a crop; sugar beets about two-thirds of a crop. Under the conditions and methods prevailing on this ditch it would seem that a duty of 91 acres per cubic foot per second is too high to produce good crops.

The following tables contain the data regarding the water used in irrigating lands under this ditch:

Water used in irrigating lands under Tanner Ditch, 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		21.8182	90.0495	32.8263	25.5867	13.0909
2		20.2314	91.8347	33.5206	24.9916	12.4959
3		20.2314	79.1405	32.5289	24.9916	11.9008
4		21.8182	67.6363	31.7355	24.3966	11.5041
5		34.9090	67.6363	26.5784	24.1982	11.7025
6		40.8594	66.2479	25.9834	23.8016	11.5041
7		41.8512	65.0578	25.3883	23.0082	11.3057
8		43.2396	63.4710	24.3966	22.6116	11.0281
9		53.1570	63.4710	24.9916	22.6116	10.8099
10		54.5454	63.4710	24.7933	22.0165	10.5719
11	19.2396	49.5867	57.5206	24.1982	21.8182	10.3537

FIG. 1.—VIEW SHOWING A FORM OF DIVIDING BOX USED IN UTAH.

FIG. 2.—DISTRIBUTING BOX, TANNER DITCH LATERAL.

Water used in irrigating lands under Tanner Ditch, 1900—Continued.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
12	18.0495	49.7851	51.7686	24.1982	21.5206	10.5719
13	18.6446	40.0660	49.9834	24.7933	21.2231	10.1355
14	19.4380	39.2726	48.3967	25.9834	21.5206	9.6793
15	6.7438	39.2726	48.3967	25.5867	21.5206	9.2429
16	7.3383	45.8182	47.2066	24.7933	21.2231	9.0248
17	....	51.1735	47.2066	28.1652	21.0248	9.0248
18	8.3306	56.1322	47.6033	27.7685	20.4297	9.2429
19	8.5289	55.7355	46.0165	27.1734	19.4380	8.8264
20	8.7272	56.5289	45.6198	26.3801	19.0413	8.5884
21	21.4215	56.5289	44.8264	25.9834	18.0495	8.3901
22	21.4215	66.4462	44.2314	25.5867	17.6528	8.5884
23	20.2314	67.0413	41.8512	25.9834	17.2562	8.8264
24	18.6446	67.6363	41.6529	25.9834	16.4628	....
25	18.0495	69.4215	40.6611	24.9916	15.8677	....
26	18.2479	72.3967	39.2726	24.3966	15.4710	....
27	18.8429	68.4297	38.6776	24.1982	14.6776	....
28	19.2396	69.8181	38.6776	23.6023	12.8926	....
29	20.8264	78.3471	40.0660	23.0082	13.0909	....
30	22.6116	79.5371	39.2726	23.0082	12.4959	....
31	....	85.0909	....	23.0082	13.0909	....
Total	314.5774	1,616.7259	1,616.9242	811.5344	613.9821	236.4094

Duty of water under Tanner Ditch, 1900.

Month.	Area.[1]	Water used.		Area per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	1,576.8	314.5774	0.20	....
May	1,576.8	1,616.7259	1.03	....
June	1,576.8	1,616.9242	1.03	....
July	1,576.8	811.5344	.51	....
August	1,576.8	613.9821	.39	....
September	1,576.8	236.4094	.15	....
Spring water	1,576.8	493.8832	.31	....
Total irrigation	....	5,704.0366	3.62	91.02
Rainfall	....	....	.49	....
Total water received	....	....	4.11	....

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 166 days.

GREEN DITCH.

The area irrigated by this ditch was 482 acres, of which about 200 acres is gravelly land, requiring much water; the remainder is gravelly or sandy loam, requiring less water. About 2,863.2 acre-feet of water was diverted, and if it had all been applied on the land it would have given a depth of 5.94 feet. The water was measured about 200 feet below the head of the ditch, and there is some loss by seepage and evaporation between that point and the irrigated land. The area irrigated per cubic foot per second was 52.09 acres. In addition to the irrigating water, the land received during the irrigating season about 0.49 foot of rainfall. The irrigating season began April 11 and closed September 23.

Grain made about two-thirds of a crop; alfalfa about five-eighths of a crop; fruit about two-fifths of a crop; potatoes a little over one-half of a crop. The duty of 52 acres per cubic foot per second is very low,

and good crops should have been raised. Perhaps too much water was used to obtain good results.

The following tables contain the data regarding the water used in irrigating lands under this ditch:

Water used in irrigating lands under Green Ditch, 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	13.0909	53.2561	15.2727	4.1653	9.4214
2	....	13.9833	56.7272	15.0743	4.0660	9.9174
3	....	11.1074	54.7438	14.4793	3.9669	10.4131
4	....	10.5124	46.1156	14.4793	6.5454	10.3140
5	....	14.8760	38.4792	14.1817	6.5454	10.5124
6	....	15.8677	38.4792	13.9835	6.1488	11.1074
7	....	21.4215	38.4792	13.4876	6.0495	11.9999
8	....	24.5949	38.4792	13.2892	6.3471	12.6942
9	....	33.1239	38.7767	14.3800	6.6445	12.6942
10	....	35.1074	39.0743	14.8760	7.1405	12.4959
11	....	40.3635	38.7767	14.7767	7.1405	12.6942
12	....	39.8677	36.0991	14.8760	7.5372	12.4959
13	....	20.8264	33.3222	14.8760	7.8346	12.6942
14	....	22.6116	32.3305	14.1817	7.8346	12.0992
15	....	21.9173	31.9339	13.4876	7.9338	12.4959
16	....	21.2231	31.9339	6.1488	8.1322	12.4959
17	....	21.9173	31.3388	6.1488	8.3306	12.2975
18	....	34.1156	31.9339	5.9504	8.9256	12.0992
19	....	36.8925	38.4792	6.4462	9.4214	11.8016
20	....	40.6611	32.9256	6.6445	9.4214	11.8016
21	12.0992	41.9503	29.5537	6.3471	9.5207	11.5041
22	12.6942	42.2479	25.6858	6.6445	9.5207	10.9091
23	12.0992	43.0413	23.2066	6.7438	10.1157	10.5124
24	8.9256	45.2231	22.1156	6.6445	9.7190	....
25	10.2148	46.6115	20.4297	6.6445	9.4214	....
26	10.4131	48.0000	20.6281	6.1488	9.7190	....
27	11.1074	48.5950	21.4215	5.9504	10.1157	....
28	11.5041	48.9917	21.4215	5.7521	10.3140	....
29	11.8016	48.9917	21.0248	5.5537	10.3140	....
30	12.2975	51.7686	21.0248	5.0578	9.9174	....
31	....	52.6611	....	5.1570	9.7190	....
Total	113.1567	1,012.1637	1,008.1964	313.6845	248.5279	267.4707

Duty of water under Green Ditch, 1900.

Month.	Area.[1]	Water used. Quantity.	Water used. Depth.	Area per cubic foot per second.[2]
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	482	113.1567	0.23	....
May	482	1,012.1637	2.10	....
June	482	1,008.1964	2.09	....
July	482	313.6845	.65	....
August	482	248.5279	.52	....
September	482	267.4707	.55	....
Total irrigation	....	2,963.1999	6.14	52.09
Rainfall	....	....	.49	....
Total water received	....	....	6.63	....

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 156 days.

FARR & HARPER DITCH.

The area irrigated by this ditch was 75 acres, all of which is sandy bottom land. About 432.5 acre-feet of water was diverted, and if it had all been applied on the land it would have given a depth of 5.77 feet. The water was measured about 1,200 feet below the head of the ditch, and as part of it spilled back into the creek, measurements at the spill were also made. No doubt there was some loss by seep-

age and evaporation in the ditch, but the percentage of loss must certainly have been much less than the loss in any of the other canals and ditches herein described. The area irrigated per cubic foot per second was 55.37 acres. In addition to the irrigating water the land received during the irrigating season about 0.49 foot of rainfall. The irrigating season began April 16 and closed September 23.

Grain made about two-thirds of a crop; alfalfa about one-half of a crop; potatoes about two-fifths of a crop. The duty of 55 acres per cubic foot per second is very low, and good crops should have been raised, unless, perhaps, too much water was used for the best results.

The following table contains the data regarding the water used in irrigating lands under this ditch:

Water used in irrigating lands under Farr & Harper Ditch, 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		2.6975	11.1868	5.5537	0.2777	0.1388
2			10.9884	5.5537	.2777	.1388
3		2.3207	11.0281	1.3884	.1983	.0694
4		2.3603	10.7306	.0992	.1983	.5355
5		2.4595	10.2942	.0793	.5157	.1785
6		3.1934	10.1950		.2181	.2974
7		3.3521	9.5405		.3570	.1785
8		3.0744	8.6083	.0793	.3570	.1785
9		2.7372	8.6678	.1587	.2974	.2380
10		2.9355	8.7868		.2380	.0595
11		2.7570	7.4380	.0397	.2777	.1785
12		2.5190	6.1001	1.1901	.5554	.1190
13			5.9504	.9719	.4959	.1586
14			5.8909	1.1702	.7735	.0991
15			5.6330	1.3686	.4959	.2181
16	1.0909		5.7124	1.1504	.3967	.3371
17	1.4281		6.3868	.5752	.3967	.3173
18	1.0909		6.5058	.5752	.4165	.2578
19	2.7372		6.0694	.6545	.3372	.3173
20	2.3405		6.2480	.7339	.2777	.0991
21	2.2215		7.0008	.7736	.1388	.1983
22	2.4000		8.2512	.8132	.1388	.1983
23	2.1421	9.5405	9.0645	.7736	.5950	.1983
24	2.0826	10.4132	10.0959	.8727	.3570	
25	2.4793	10.8298	8.9653	.9719	.0595	
26	2.4793	11.0678	8.2512	1.0711	.0793	
27	2.3405	7.7157	6.9818	1.1107	.0793	
28	2.7372	7.6165	6.8033	1.0711		
29	2.7372	8.0529	6.6248	.9124		
30	2.8760	8.4297	6.4463	.8132		
31		9.9067		.7736		
Total	33.1833	114.0694	240.4554	31.2991	8.7061	4.6097

Duty of water under Farr & Harper Ditch, 1900.

Month.	Area.[1]	Water used.		Area per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	75	33.1833	0.44	
May	75	114.0694	1.52	
June	75	240.4554	3.21	
July	75	31.2991	.42	
August	75	8.7061	.12	
September	75	4.6097	.06	
Total		432.3230	5.77	55.37
Rainfall			.49	
Total water received			6.26	

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 161 days.

LOWER CANAL.

The area irrigated by this canal was 585.3 acres, all of which is bottom land, about two-thirds of it being a rich, black loam, and the remainder light clay soil. About 1,791 acre-feet was diverted from the creek and from springs, and if it had all been applied on the land it would have given a depth of about 3.06 feet. The water was measured about 600 feet below the head of the canal, and there was some loss by seepage and evaporation between that point and the lands irrigated, but the percentage of loss would certainly be much less than in the ditches which irrigate the porous bench lands. The area irrigated per cubic foot per second was 107.59 acres. In addition to the irrigating water the land received during the irrigating season about 0.49 foot of rainfall. The irrigating season began April 11 and closed September 23.

Grain and fruit made a fair crop, being about five-sixths of what is called a good crop; alfalfa, about two-thirds of a crop; potatoes, about three-fifths of a crop. Under the conditions and methods prevailing on this canal it is probable that a duty of 100 acres per cubic foot per second is a little too high for this land.

The following tables contain the data regarding the water used in irrigating lands under this canal:

Water used in irrigating lands under Lower Canal, 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet*
1	....	5.5537	23.4049	10.3140	6.9421	5.7521
2	....	5.9504	23.0082	10.1157	6.7438	5.5537
3	....	6.1488	23.2066	12.8926	6.5454	5.3554
4	....	6.1488	23.2066	13.4876	6.3471	5.1570
5	....	7.1405	21.0248	13.9833	6.3471	4.9587
6	....	7.5372	20.8264	13.4876	6.1488	4.7604
7	....	9.5207	20.8264	13.4876	6.0495	4.5619
8	....	9.3223	20.8264	13.0909	5.7521	4.3636
9	....	8.9256	20.8264	9.3223	5.7521	4.1653
10	....	13.6859	20.6281	6.7438	5.7521	3.9669
11	4.3636	14.6776	20.0530	5.1570	5.7521	3.9669
12	4.7604	15.0743	19.8347	4.7604	5.5537	3.9669
13	5.1570	10.3140	20.2314	4.9587	5.5537	3.7686
14	5 5537	10.9091	20.4297	4.9587	5.5537	3.7686
15	5.9504	16.0661	20.0330	5.7521	5.7521	3.3719
16	7.5372	16.8596	20.0330	6.1488	5.1570	3.3719
17	10.1157	16.4628	20.2314	6.1488	4.9587	3.3719
18	4.7604	17.2562	20.2314	5.9504	5.1570	3.1736
19	4.7604	18.2479	11.8016	5.9504	5.0578	2.9752
20	5.5537	18.4462	9.9174	6.3471	4.7604	2.9752
21	4.9587	18.2479	9.7190	6.7438	4.3636	3.1736
22	4.9587	18.0495	9.7190	7.0412	4.3636	3.0743
23	5.5537	19.1404	10.5124	6.7438	4.7604	3.0743
24	5.9504	18.9420	10.7107	6.7438	5.0578	....
25	5.5537	23.6033	10.9091	6.3471	5.1570	....
26	5.9504	29.5537	11.1074	6.3471	5.5537	....
27	6.9421	32.1322	10.9091	6.3471	5.3554	....
28	7.1405	27.7685	10.4131	6.9421	5.0578	....
29	7.1405	23.2066	10.5124	7.1405	4.7604	....
30	7.7355	23.2066	10.5124	6.5454	4.5619	....
31	....	23.2066	....	6.7438	5.1570	....
Total	120 3967	491.3049	505.5860	246.7435	169.7849	92.6279

Duty of water under Lower Canal, 1900.

Month.	Area.[1]	Water used.		Area per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	585.3	120.3967	0.21	
May	585.3	491.3049	.84	
June	585.3	505.5860	.86	
July	585.3	246.7435	.42	
August	585.3	169.7849	.29	
September	585.3	92.6279	.16	
Spring water	585.3	164.6277	.28	
Total irrigation		1,791.0716	3.06	107.59
Rainfall			.49	
Total water received			3.55	

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 166 days.

BIG DITCH.

The area irrigated by this ditch was 1,813.5 acres, all of which is bottom land, except about 250 acres of sandy bench land near Jordan River. About 900 acres of the bottom land is a light clay soil; the remainder is a rich, sandy loam. It is all good land, except 320 acres of pasture, which is wet land, requiring only one or two irrigations during the season. About 5,164 acre-feet of water was diverted from the creek and from the springs, and if it had all been applied on the land it would have given a depth of 2.85 feet. The water was measured about 500 feet below the head of the ditch, and there was some loss by seepage and evaporation between that point and the lands irrigated, but the percentage of loss should be much less than in the ditches which irrigate the porous bench lands, although probably more than in the lower canal. The area irrigated per cubic foot per second was 115.63 acres. In addition to the irrigating water, the land received during the irrigating season about 0.49 foot of rainfall. The irrigating season began April 11, and closed September 23.

Grain made a fair crop, being about five-sixths of a good crop; alfalfa about five-eighths of a crop; fruit and potatoes about one-half of a crop; sugar beets made a good crop. Under the conditions and methods prevailing on this ditch, it is probable that a duty of 100 acres per cubic foot per second is about right for this land.

The following tables contain the data regarding the water used in irrigating lands under this ditch:

Water used in irrigating lands under Big Ditch, 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		11.5041	82.1157	15.3718	24.3966	9.9174
2		11.7025	82.1157	15.0743	23.8016	9.5207
3		11.3057	82.1157	19.2396	23.6033	8.8263
4		11.5041	82.7107	20.2314	23.2066	8.4298
5		12.8926	80.7272	21.2231	22.1156	7.9388
6		14.0826	76.7603	22.6116	22.1156	7.9388
7		22.4132	68.4297	23.6033	22.1156	7.9388
8		17.6528	53.5537	24.7932	20.6281	7.5372
9		13.4876	48.9917	24.7933	19.8347	7.1405
10		16.4628	48.1983	24.7933	18.4462	6.9421

Water used in irrigating lands under Big Ditch, 1900—Continued.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
11	8.7272	19.6363	40.2644	23.6032	17.6528	6.6445
12	11.3057	28.3636	40.2644	23.8016	15.8677	6.6445
13	10.8098	20.4297	40.6611	25.5867	14.0826	6.9421
14	11.3057	21.0248	40.2644	24.3966	14.3800	6.7438
15	10.8098	24.7933	43.8347	24.9916	14.3800	6.6445
16	12.8026	42.8429	47.1073	25.3883	14.0826	6.4462
17	19.0413	48.9917	48.0000	26.1817	13.6859	6.2479
18	9.7190	50.7768	49.3884	26.5784	13.6859	5.9504
19	10.3140	52.7603	46.4132	26.5784	13.6859	5.7521
20	10.8098	53.5537	42.4463	26.7768	13.3883	5.5537
21	10.3140	61.2892	34.9090	26.5784	13.0909	5.1570
22	10.8098	60.8925	30.9421	25.5867	12.6942	4.9587
23	11.3057	61.3859	27.5701	25.3883	12.4959	8.7272
24	11.5041	62.9751	25.9834	25.5867	12.1983	....
25	11.3057	68.7272	24.9916	24.9916	11.9008	....
26	16.6611	69.6198	25.5867	24.7933	11.9008	....
27	13.6859	71.6033	24.7933	23.8016	11.7025	....
28	14.2809	76.3636	24.1982	24.1982	11.3057	....
29	15.0743	80.7272	23.8016	24.7933	11.1074	....
30	15.0743	81.1239	23.8016	25.3883	10.8099	....
31	....	81.5206	....	25.3883	10.3736	....
Total	245.7507	1,282.7094	1,410.9405	762.1131	494.7356	164.5429

Duty of water under Big Ditch, 1900.

Month.	Area.[1]	Water used. Quantity.	Water used. Depth.	Area per cubic foot per second.[2]
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	1,813.5	245.7507	0.14	....
May	1,813.5	1,282.7094	.71	....
June	1,813.5	1,410.9405	.78	....
July	1,813.5	762.1131	.42	....
August	1,813.5	494.7356	.27	....
September	1,813.5	164.5429	.09	....
Spring water	1,813.5	823.1442	.45	....
Total irrigation	....	5,183.9364	2.86	115.63
Rainfall	....	....	.49	....
Total water received	....	....	3.35	....

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 166 days.

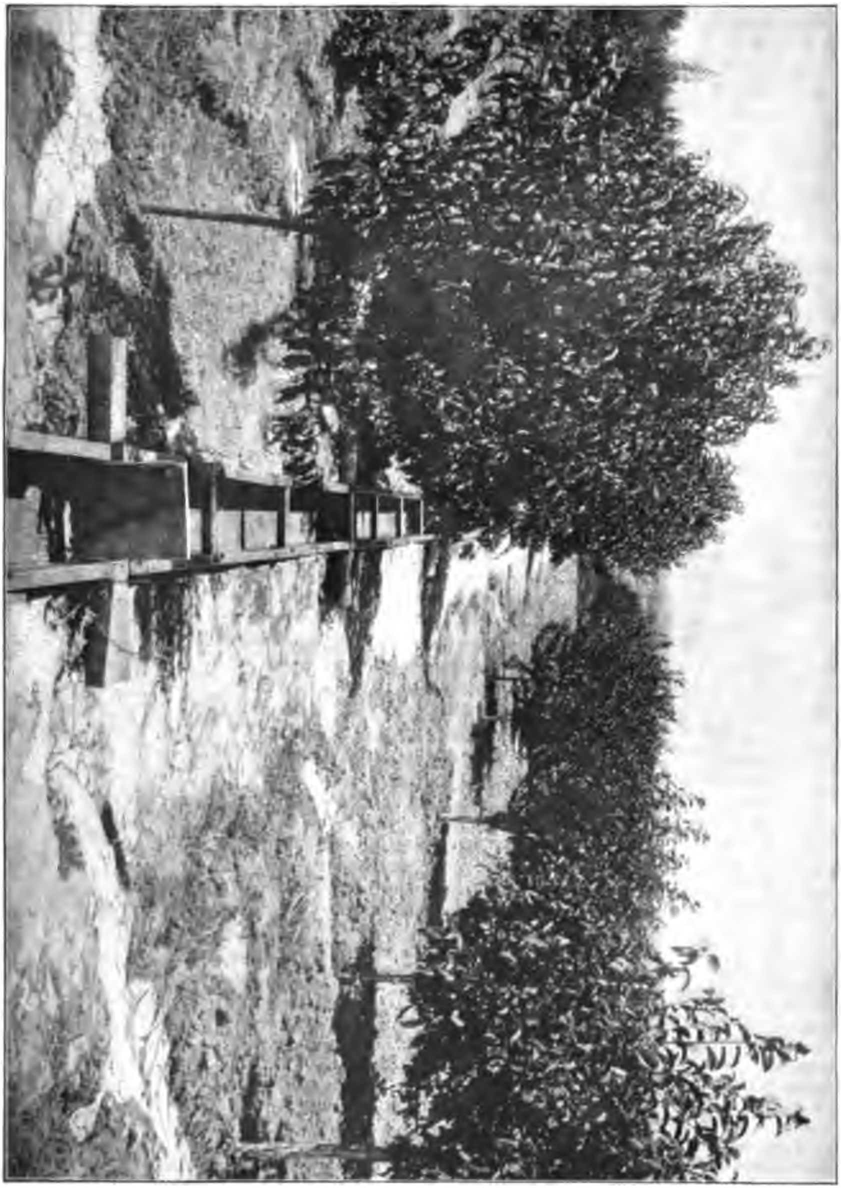
ACREAGE, CROPS, AND YIELD.

The following table shows the acreage and the yield for the lands under each canal and ditch:

Acreage and yield for each canal and ditch.[1]

Crop.	Butler Ditch. Acres.	Butler Ditch. Yield.	Brown & Sanford. Acres.	Brown & Sanford. Yield.	Upper Canal. Acres.	Upper Canal. Yield.	Tanner Ditch. Acres.	Tanner Ditch. Yield.
Wheat	....	....	148.50	2,804	130.91	4,065	168.50	547
Oats	....	....	7	176	63.41	2,908	46	1,738
Barley	....	....	....	....	3.25	161	1.50	80
Corn	....	....	28.24	315	49.12	1,213	63.50	1,896
Hay	118.50	213	717.50	1,154	1,033.45	2,501	880.08	2,706
Pasture	....	....	83	....	40	....	300.95	....
Small fruit	1.25	4,870	4.24	14,460	20.95	48,720	2.67	8,567
Large fruit	6	130	22.58	1,158	142.41	7,680	40.75	5,933
Vegetables	....	$25	.19	$85	10.40	$1,008	20.75	$1,680
Potatoes	.75	150	17.25	1,700	40	5,319	52.10	8,889
Total	126.50	....	1,028.50	....	1,533.90	....	1,576.80	....

[1] In this table the yields of wheat, oats, barley, corn, large fruit, and potatoes are given in bushels; the yields of hay in tons; the yields of small fruits in quarts; the yields of vegetables in dollars. Pastures were irrigated, and therefore their acreage is included in the total areas watered.



VIEW SHOWING A METHOD OF ORCHARD IRRIGATION IN UTAH.

Acreage and yield for each canal and ditch—Continued.

Crop.	Green Ditch.		Farr & Harper.		Lower Canal.		Big Ditch.	
	Acres.	Yield.	Acres.	Yield.	Acres.	Yield.	Acres.	Yield.
Wheat	19.75	448	10	288	85	2,863	230.50	6,771
Oats	6.50	213	2.25	75	10.66	606	119.50	5,020
Barley	2	50	....	....	10.50	490	5	280
Corn	36	1,145	5.50	160	54.60	1,889	118.50	5,647
Hs	235	540	34.25	59	260.75	1,077	812.08	2,118
Pastur	137.75	....	20	....	27	....	321.90	....
Small fruit	1.75	2,415	....	....	11.56	41,251	4.43	7,805
Large fruit	26.20	3,024	....	....	62.53	3,899	53.16	6,336
Vegetables	3.35	$164	.50	$40	6.60	$765	13.81	$870
Potatoes	13.70	2,252	2.50	285	56.10	9,369	134.62	21,365
Total	482	....	75	....	585.30	....	1,813.50	....

The following were the average prices for produce delivered in Salt Lake City, 6 to 14 miles distant: Wheat, 50 cents per bushel; oats, 35 cents per bushel; barley, 56 cents per bushel; corn, 50 cents per bushel; large fruit, 75 cents per bushel; small fruit, 8 cents per quart; potatoes, 35 cents per bushel; hay, $9.50 per ton.

None of these crops was damaged by frosts, except strawberries, which made only about one-half of a crop on that account. The water in Big Cottonwood Creek was lower than it had been for a number of years, and most of the canals and ditches were short of water during the latter half of the irrigating season. As a general rule the farmers irrigated the fruit, vegetables, and potatoes first, and let the alfalfa have only what water might be left after the more valuable crops had been watered

GENERAL REMARKS.

In order to make a thorough study of the subject of duty of water in a locality like the one covered by this report, where eight canals are used to irrigate 7,221.5 acres of land, the special agent should spend all of his time on the ground during the irrigating season. More attention should be paid to the classification of the different kinds of lands, and accurate data should be secured as to the number of acres of each kind—the classification of the different kinds of lands given in this report being only approximate. Not only should this be done, but the average depths of the different surface soils should be determined, as well as the nature of the subsoils. Data should be secured showing what percentage of the water is lost by seepage and evaporation in the main canals and laterals; how much water is used at each irrigation; how much is used on each of the different kinds of crops; how frequent the waterings should be for different crops on different soils, etc. The amount of money allowed for making the investigations is too small to permit of all this work being done, but some information has been obtained by talking with the farmers, which is here given, although it is, of course, not exact,

When making the first irrigation in the spring more time is required to get the water over the ground than for any of the succeeding irrigations. In a general way, it may be said that for alfalfa it requires twice as long; for plowed land, about three times as long. The frost seems to open up the ground, and the first irrigation packs it and makes it more solid, so that afterwards the water goes over it much faster. The time required depends upon the slope of the ground, as well as upon the nature of the soil; but, under similar conditions as to slope, gravelly land requires more time than any other kind. In irrigating gravelly land, the best way is to water only a portion of it, and then change the water to some other piece of land, allowing the watered portion of the gravelly land time to pack. Then turn the water back on the gravelly land and it will travel very quickly over the portion first watered, reaching the unwatered portion before much water is absorbed by the watered portion.

The farmers claim in a general way that light clay land, very sandy land, and gravelly land should be irrigated about three times, as compared with twice for loam. If plowed deep in the fall any kind of land will require less water than if it is merely "scratched." Sandy land gradually improves with irrigation, changing to a sandy loam in seven or eight years. Sandy loam, with a flat slope and a clay subsoil, when irrigated late in the winter or early in the spring in nonfreezing weather, will produce one or two good crops of alfalfa without further watering. In hot weather it is best to irrigate sandy land at night; if the water is put on in the daytime it is liable to "scald" the crop.

Comparatively flat light clay land is said to produce the most alfalfa. The first crop of alfalfa is generally cut early in June on the bench land, and about the middle of June on the bottom land; second crop, about the 24th of July on the bench land, and about the 1st of August on the bottom land; the third crop is allowed to grow as long as it is safe from frost, being generally cut about the 1st of October, although sometimes it is cut in September and sometimes not until the middle of October. Alfalfa should be plowed under every eight or ten years and the land planted in grain. For two years after alfalfa has been plowed under wheat will make nearly twice the usual crop.

As a general thing, it is customary to irrigate grain three times to make a crop, although frequently four irrigations are required on bench lands, while sometimes only two are required on bottom lands. Grain should be irrigated only when it is necessary; if irrigated too often it makes too much straw and is likely to fall down. When wheat is irrigated three times, it is usual to water it the first time when it is "in the boot," generally from the 1st to 10th of June; the second time, when it heads out; the third time, when it is "in the dough," just before it begins to ripen. It is customary to irrigate oats three times to make a crop, although sometimes four waterings are neces-

sary on bench lands. The first irrigation is generally about June 1. Barley requires about the same treatment as wheat and oats, but ripens a little earlier than wheat. On sandy loam, thoroughly cultivated, corn will usually not need any water until it tassels out. Comparatively flat light clay land and black loam produce the best grain.

IRRIGATION UNDER CANALS FROM LOGAN RIVER.

By GEORGE L. SWENDSEN,
Professor of Irrigation Engineering, Utah Agricultural College.

OUTLINE OF INVESTIGATIONS.

During the summer of 1899 duty of water investigations were made on the Logan and Richmond Canal, the largest canal supplied by Logan River. At first it was difficult to create any interest among the irrigators, but before the season's work had closed, and when the plan and purpose of the work came to be understood, not only were the owners of the Logan and Richmond Canal interested in the results of the work, but many of the farmers under other canals in the same locality became anxious to see the work extended to their canals during the season of 1900.

The officers of the Logan, Hyde Park, and Smithfield Canal Company offered to supply all labor and material necessary for the establishment of measuring stations, etc., on their canal if it could be included in the investigations of 1900. When this proposition was called to the attention of this Department, it was at once decided to include this canal in the work of the present season, and the canal company began at once the construction of the three measuring flumes used in making the observations reported in the following pages.

The work of the season has therefore included these two canals, the investigations pertaining mainly to duty of water and seepage losses, though the grade, cross section, methods of distribution, etc., have also received consideration.

Conditions have been unusually favorable for the work during the season, first, on account of the necessity which arose during the months of July and August for a careful distribution of the water on account of the limited supply, and, second, because of the general interest in irrigation questions developed among the irrigators of this locality during the past year.

It is the purpose of the writer to outline in the following pages such information relative to the questions considered as has been gathered from field observations, correspondence, and personal talks with irrigators and reports from water masters and other canal officers.

LOCATION AND SIZE OF THE CANALS.

The map forming a part of this report shows the relative location of the Logan River, which supplies the water, the two canals, and the lands irrigated (fig. 18).

The Logan, Hyde Park and Smithfield Canal made its first appropriation of water in 1882. The first 7,000 feet of the canal is constructed on a steep mountain side, necessitating considerable rock work. The grade in this portion of the canal, though not uniform, averages 3.10 feet in 1,000. In the remaining 7 miles of its length the average grade is 1.35 feet in 1,000. The total area supplied with water is 3,200 acres, but all is not cultivated each year, and hence the actual acreage irrigated is somewhat less. During the season of 1900 2,890 acres were irrigated.

The Logan and Richmond Canal is 10.5 miles long and has a fairly uniform grade of 0.65 foot per 1,000.

The nominal area irrigated is 3,270 acres, but the actual acreage irrigated is less for the same reason as given for the Logan, Hyde Park, and Smithfield Canal. In 1899 this area was 2,894 acres, and in 1900 it was 3,040 acres.

Both canals are supplied with water from Logan River, the minimum discharge of which during 1900 was 220 cubic feet per second; the maximum was 1,006 cubic feet per second, and the mean for the four months—June, July, August, and September—423 cubic feet per second.

CONTROL AND OPERATION.

LOGAN, HYDE PARK, AND SMITHFIELD CANAL.

The Logan, Hyde Park, and Smithfield Canal is owned and operated by a stock company of 151 farmers and has a capital stock of $20,000 in shares of $5 each, 2,481 of which are fully paid up.

The stock certificates do not specify in any way the volume of water that the holder of them is entitled to, but represent shares in the canal system. These permit the owners to use proportionate parts of the water furnished by the canal.

In the beginning of each irrigation season the officers of the company issue to each stockholder printed regulations under which the water will be distributed during that season. A copy of this notice is given below:

Notice of apportionment of water.

OFFICE OF THE
LOGAN, HYDE PARK, AND SMITHFIELD CANAL COMPANY,
Logan, Utah, May 13, 1900.

Mr. ——— ———,
——— ———:

You are hereby notified that the water owned by the Logan, Hyde Park, and Smithfield Canal Company, and flowing in its canal during the irrigation season of 1900, will be distributed by the water master to the stockholders according to the stock owned by them, respectively, as shown by the books of the company.

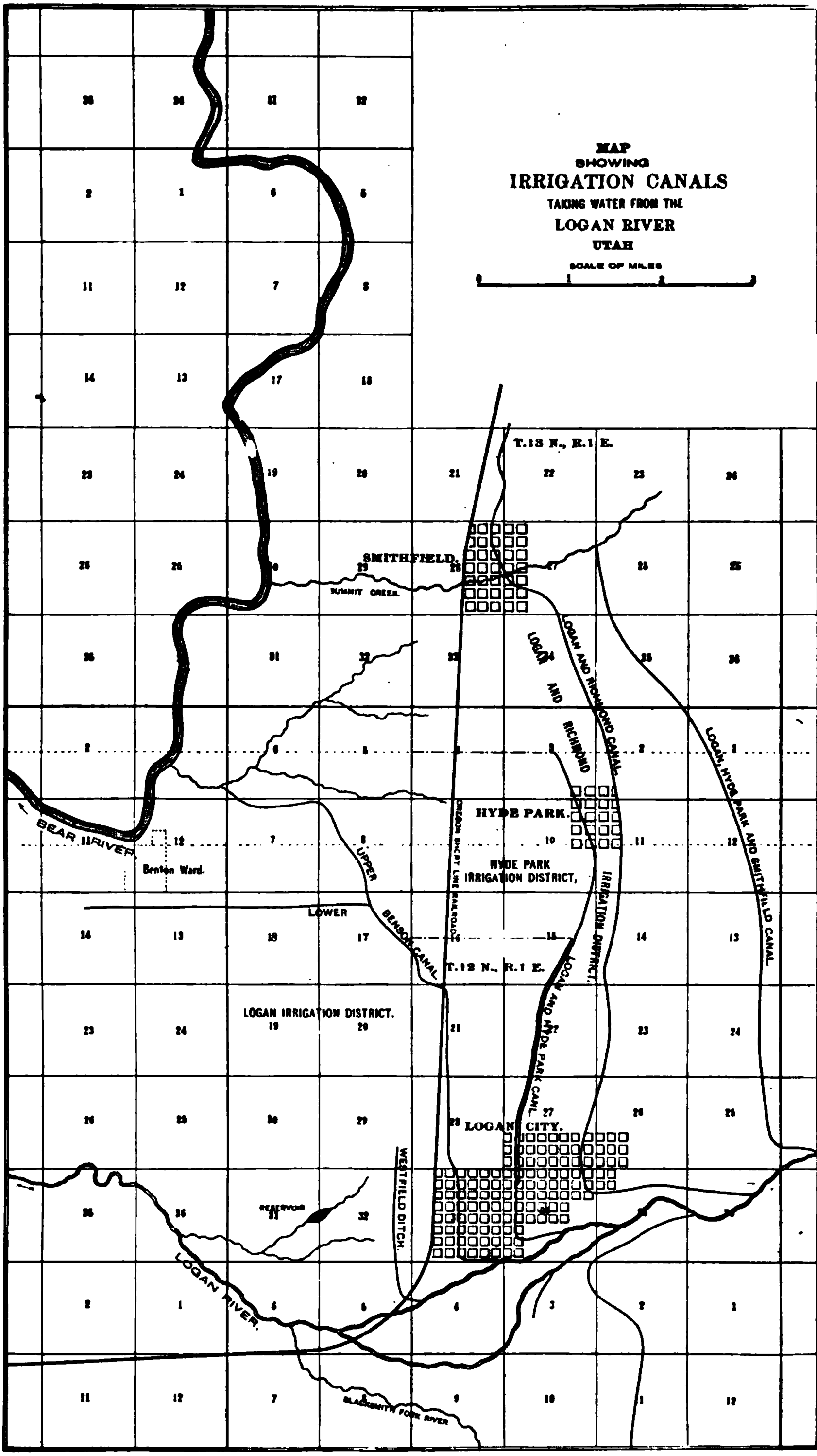


FIG. 18. - Map showing irrigation canals taking water from Logan River, Utah.

Each share of stock will entitle the owner to the use of what is commonly called "an irrigating stream" for seventeen hours.

The books of the company show that you are the owner of —— shares of stock, and you will therefore be entitled to the use of "an irrigating stream" for —— hours, provided no man shall draw more than one-half of his time at the first watering.

By order of the board of directors.

LARS C. PETERSON, *Secretary.*

At the annual meeting of the stockholders the maintenance assessment for the season is determined upon and levied in accordance with the officers' estimate of the probable cost of operation for the following year. The form of assessment notice is given below:

Notice of assessment.

THE LOGAN, HYDE PARK AND SMITHFIELD CANAL COMPANY.
(Location of principal place of business, Logan City, Utah.)

Notice is hereby given that at a meeting of the directors, held on the —— day of ——, 189—, an assessment of —— per share was levied on the capital stock of the corporation, payable to —— ——, treasurer of said corporation, at ——, in Logan City, Utah, on or before the —— day of ——, 189—.

Any stock on which this assessment shall remain unpaid on the —— day of ——, 189—, will be delinquent and advertised for sale at public auction, and, unless payment is made before, will be sold on the —— day of ——, 189—, to pay the delinquent assessment, together with the cost of advertising and expense of sale.

—— ——, *Secretary.*

The total cost of operation for the season of 1900 amounted to 50 cents per share of stock, a total of $1,240.50. A large proportion of this sum was expended in the annual repairs on the canal.

LOGAN AND RICHMOND CANAL.

The Logan and Richmond Canal system is managed by the 392 owners, organized as an irrigation company under the law passed in 1865. Under the regulations of this organization there is issued by the secretary to each shareholder in the canal a certificate designating the number of acres his interest entitles him to irrigate each year. The basis for the certificates is the irrigator's interest in the canal, as shown by the books of the organization. The number of acres for which he receives water is to the total area irrigated by the canal as his interest is to the total value of the canal. An acre's claim in this canal cost the original owners between $18 and $20. There is no definite understanding as to the volume of water represented by an acre claim, but it depends, with but slight limitations, on the needs of the different crops and lands.

At the stockholders' annual meeting, usually held in the early part of each year, the annual maintenance tax is determined upon in accordance with the officers' estimate of the probable cost of operation for the following year. The tax for the season of 1900 was 55 cents per acre, or a total of $1,793, to cover all repairs on the canal, per diem pay of officers, ditch rider, and water masters, and operating

expenses in general. The regulations provide that the board of trustees may make special assessments in cases of emergency.

WATER DISTRIBUTION.

LOGAN, HYDE PARK, AND SMITHFIELD CANAL.

The articles of incorporation provide that the water of the canal shall be distributed to users by water masters appointed by the board of directors of the company. Up to the present time one man has been appointed for the irrigation season, whose duty it is to make daily trips along the first 5 miles of the canal to divide the water among irrigators located thereunder and see that a certain portion of the water passes on to the remaining 3 miles of the system. It will be seen in the notice of apportionment given above that his unit of measurement is the "irrigating stream." No gage or measuring apparatus of any kind is provided to aid the water master in his work, but his experience enables him to estimate the number of "irrigation streams" his canal carries, and he distributes them among the irrigators in rotation according to the order of their applications for water, subject to the provisions of the notices of apportionment mentioned above. At each point of diversion from the canal the company provides a gate of the ordinary rectangular box form, but no rating of its discharge is made for the use of the water master. The boxes are variable in size and are not placed on a uniform grade; hence they are of but little aid in the task of dividing the water. However, these are the only measuring devices furnished, and the division of water therefore rests almost entirely on the estimate of the water master.

During the summer the writer made a series of measurements, by means of portable weirs, of a number of the irrigating streams thus apportioned to the irrigators. The results of these are given in the following table, together with the size of the gate and the head on the opening. The irrigating streams are supposed to be equal. That they are not is shown by the last column of this table.

Results of measurements of irrigating streams, July 17, 1900.

Size of gate. Width.	Size of gate. Depth.	Head on center of opening.	Number of "irrigation streams."	Volume.	Equivalent volume of one "irrigation stream."
Feet.	*Feet.*	*Foot.*		*Cu. ft. per sec.*	*Cu. ft. per sec.*
1	0.80	0.80	1	1.96	1.96
.72	.56	.93	¾	1.52	2.02
1.10	.90	.55	¼	.78	3.12
.68	.85	.82	¾	1.42	1.89
.86	1	.74	1	1.78	1.78
.93	1.10	.90	1¼	1.90	1.47
.71	.63	.81	1	1.62	1.62
.65	1	.70	1	1.54	1.54
1	.73	.60	1	.85	.85
1.20	.90	.80	½	1.23	2.46
1.10	.85	.75	½	1.27	2.54
.90	.80	.60	1	1.67	1.67
1.10	.90	.80	2	2.06	1.03

The division of the water in the last 3 miles of the canal is in charge of a local water master employed by the canal company, though the regular water master makes an occasional trip over that portion of the system also. The division there is accomplished in exactly the same way as in the other part of the canal.

The last clause in the apportionment notice copied above may need some explanation. The water is distributed on the rotation plan, with about 20 irrigators using water at a time. If each of the 20 irrigators owned 20 shares of stock and all their crops were such that one irrigation would bring them through the season, these 20 irrigators might call for their entire allotment at one time, and so use the whole canal for a period of fourteen days. Three such periods utilized by 60 of the 151 shareholders in the canal, representing less than one-half of the capital stock, would certainly be fatal to the irrigation interests of the other 91 stockholders. For this reason a provision is made that only one-half of a stockholder's allotted claim can be demanded before all other applicants have had a like portion of their claims supplied.

LOGAN AND RICHMOND CANAL.

In the case of the Logan and Richmond Canal, while the general plan of distribution is the same as outlined above, the rights of the irrigator are based on the acre as a unit, and the results secured are much more satisfactory. The duties of the water masters are correspondingly more definite. They are aware that a definite area is to be irrigated and regulate the distribution with that end in view.

To facilitate the work, the canal is divided into three sections. The first 5.5 miles is known as the first or Logan section, the next 3 miles as the second or Hyde Park section, and the remainder the third or Smithfield section. Three water masters are employed to manage the distribution. One of these, called the head water master, is the ditch rider of the whole canal, and also has charge of the headgates and attends to the details of the distribution in the first section, besides having general supervision of the distribution along the whole canal system. The other two are in charge of the distribution in sections 2 and 3. The capacity of the canal, after the appropriation for the city lots irrigated in Logan City is deducted, is supposed to be thirty irrigating streams. It is the duty of the head water master to distribute eleven of these streams in the first section of the canal, to allow the water master of the second section to distribute eight streams in that part of the district, and to see that eleven streams pass on to the third section to be distributed by the water master there. In making this division the water master depends entirely on his own judgment as to accuracy, there being no mechanical means provided to test the division.

In all three sections the water is distributed among the irrigators

on the rotation plan. In the first and second sections the requirements of the land are less than those of the third section, and in these two the water masters are generally able to supply all demands of shareholders; but in the third section, where there is a gravel soil and a great deal of water is needed, by an agreement of those interested in that section the water is distributed on a time basis, one-eleventh of the whole supply for Smithfield being allowed for a period of five hours for each acre of water right. In the case of the small shareholders of Logan City, who irrigate small garden tracts, the water master apportions a stream to a number of them in common, and they arrange the division among themselves, usually on a time basis.

The ordinary rectangular box gate, supplied with a lock, is installed at each point of diversion from the canal. It is usually found necessary to lock the gates in position. In the construction of the gates no attempt was made to have them uniform. In the following table is given the results of weir measurements made at points of diversion during the season of 1900:

Measurements of diversion from Logan and Richmond Canal, August 30, 1900.

Depth of opening.	Width of opening.	Head on center of opening.	Volume.	Number of irrigators.	Gate capacity.
Feet.	*Feet.*	*Feet.*	*Cu. ft. per sec.*		*Cu. ft. per sec.*
0.83	1.05	1.54	1.15	1	1.40
1	.50	1.20	1.65	2	1.78
1	.52	1.37	1.04	1	1.52
.80	1	.80	2.06	2	2.06
.91	1.10	.82	1.16	1	1.63
.90	.94	.73	.94	1	1.55
.85	.72	.86	1.28	1	1.71
1.10	1	1.15	2.81	2	3.28
1	.86	.73	1.15	1	2.31
.97	1.10	.61	2.91	2	3.10

The manner in which the use of water is controlled on these two canals makes it possible to attain a higher duty of water than could be secured if each irrigator was furnished with a continuous stream of water whose volume was limited by his interest in the canal.

The number interested in the two canals is 543, and the total area irrigated by them is 6,470 acres, making the average area of the farms a fraction less than 12 acres, and the distribution of the water is so managed that the great majority of these stockholders are very well satisfied with results; and, since there are rarely any losses from drought, great credit is due the officers of the companies. Such results obtained from canals built, owned, and operated by the farmers themselves speak well for that method of canal management.

When the financial features are considered, the results are very favorable. The two canals have cost about $60,000. The records of the companies indicate that the greater part of this amount was worked out by the farmers themselves at a liberal wage rate. The total cost of repairs and maintenance for the season of 1900 was $3,038, fully three-fourths of which was paid in labor. The annual

interest on the $60,000 originally invested, at 7 per cent, is $4,200. Adding to this the annual cost of maintenance makes an annual outlay of $7,238. The total acreage irrigated being 6,470, the annual cost is a fraction over $1.13 per acre, which is a low price for water for a canal built at such an early date, when labor and material were expensive.

There is an urgent demand for improvement in some details of the water distribution. The responsibility placed upon the water masters of both canals is great, and they should be provided with measuring devices for dividing the water. In the opinion of the writer, a radical change from the present system is not needed. The present system of gates should be remodeled and arranged in groups according to size. The grade, head on the opening, and all the conditions should be made uniform in the gates of each group. A rating of a single gate in each group would then suffice for the determination of the discharge for all heights of gate opening and heads. The uniformity of grade in both canals would permit of such an arrangement, and the sizes of streams diverted at the various gates is such that not more than three groups of gates would be needed on each canal, necessitating three ratings of gate capacity and three rating tables. Copies of these could be in the hands of all irrigators as well as water masters.

For the purpose of the division of water among different sections of the canal, rating flumes provided with gages should be established at the section limits. A rating of these would enable the ditch rider to divide the water with considerable accuracy. In this division the question of seepage losses should be considered, so that the right of the irrigator at Logan may mean the same in volume of water as does that of the Smithfield farmer, 8 miles farther down the canal.

SEEPAGE AND EVAPORATION.

In the spring of 1899 measurements were begun on both of these canals to determine the losses by seepage and evaporation, and, though somewhat changed in plan, these investigations were continued during the summer of 1900. In 1899 the work was carried on by means of measurements of losses in different sections all along the line of both canals. Measurements were made above and below points where water was taken from the canals, so that the losses were determined in the sections of the canals between these places. All measurements were made carefully with a water meter, and the results are thought to be reasonably accurate. For the work of 1900 a section of each canal was chosen, and all measurements confined to regular stations. In the Logan, Hyde Park, and Smithfield Canal the first 7,180 feet of the canal was chosen, there being no points of diversion in that length. For that distance the construction is on a steep mountain side and the conditions are such that seepage is considerable, as may be seen from the results. The upper gagings were

made at the flume built for duty of water measurements. At the lower end of the section a similar flume was constructed and all conditions made favorable for careful measurements at both places.

On the Logan and Richmond Canal there are a number of flume sections in the first 9,000 feet of length, and two of these, 7,600 feet apart, were chosen and placed in such condition that measurements could be carefully made. At these four stations careful meter measurements were made each week. The single diversion from this section of the Logan and Richmond Canal was measured by a weir at the same time. The results of these investigations are given in the following table:

Measurements of losses by seepage and evaporation.

Date.	Interval between measurements.	Length of section.	Wetted perimeter.	Width of water surface.	Temperature of water.	Volume, upper end of section.	Volume, lower end of section.	Volume lost.	Percentage lost.	Loss per 1,000 feet.
	Min.	*Feet.*	*Feet.*	*Feet.*	°*F.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*	*Per cent.*
LOGAN AND RICHMOND CANAL.										
May 29, 1899	30	2,720	18.20	14.70	46	72.43	71.02	1.41	*c* 1.95	0.72
Do	35	2,900	19	14	47	69.69	68.80	.89	*a* 1.28	.44
Do	50	3,750	18.35	14.20	49	58.62	56.62	2	*b* 3.41	.91
July 31, 1899	40	2,900	19.10	14.50	55	85.71	84.32	1.39	*a* 1.62	.56
Do	40	3,750	20	15.10	54	84.26	81.75	2.51	*b* 2.98	.79
Do	90	8,000	18.22	14.70	52	76.69	75.75	.94	1.23	.41
Aug. 1, 1899	15	1,600	19.30	15.60	56	69.44	69.09	.35	*d* .50	.31
Do	40	1,600	19.30	14.70	57	75.20	74.87	.33	*d* .44	.28
Do	45	2,720	18	13.40	57	68.99	67.73	1.26	*c* 1.83	.67
Aug. 2, 1899	50	4,450	16.80	12.30	58	58.69	55.97	2.72	4.63	1.04
Do	40	1,500	18.10	14	54	50.02	50.30	[1].28	[1].50	....
Do	90	1,140	17	14	53	36.12	35.94	.18	.50	.44
Average.	....	....	....	....	....	....	....	....	....	.60
July 6, 1900	60	7,600	18.40	13.20	49	91.59	84.18	7.41	8.09	....
July 18, 1900	60	7,600	18.40	13.20	50	87.93	79.64	8.29	9.43	....
July 21, 1900	60	7,600	18.40	13.20	51	84.98	78.25	6.73	7.92	....
July 28, 1900	60	7,600	18.40	13.20	53	87.86	79.74	8.12	9.24	....
Aug. 11, 1900	60	7,600	18.40	13.20	51	75.81	68.67	7.14	9.41	....
Aug. 18, 1900	60	7,600	18.40	13.20	52	64.41	57.69	6.72	10.43	....
Average.	....	....	....	....	....	....	....	....	9.87	....
LOGAN, HYDE PARK, AND SMITHFIELD CANAL.										
May 30, 1899	60	2,450	15.10	13.60	43	52.78	52.12	0.66	1.25	0.51
Do	30	1,290	14.60	12.90	44	51.43	51.19	.24	.47	.36
Do	60	5,000	17.10	14.20	44	47.03	45.07	1.96	4.17	.83
Do	15	2,500	18.35	16	45	41.07	40.02	1.05	2.56	1.02
Do	40	1,750	17.63	14.50	48	37.83	37.33	.50	1.32	.75
Do	40	2,500	21.30	17.90	48	36.66	35.84	.82	2.24	.90
Average.	....	....	....	....	....	....	....	....	....	.73
July 7, 1900	120	7,180	17.10	14.20	51	58.46	53.10	5.36	9.17	....
July 12, 1900	120	7,180	17.10	14.20	50	56.17	54.40	1.77	3.15	....
July 21, 1900	120	7,180	17.10	14.20	52	58.57	52.61	5.96	10.17	....
Aug. 7, 1900	120	7,180	17.10	14.20	51	54.32	49.12	5.20	9.57	....
Aug. 11, 1900	120	7,180	17.10	14.20	53	53.02	48.07	4.95	9.24	....
Aug. 18, 1900	120	7,180	17.10	14.20	55	45.47	39.83	5.64	12.41	....
Aug. 25, 1900	120	7,180	17.10	14.20	52	41.12	37.29	3.83	9.32	....
Sept. 1, 1900	120	7,180	17.10	14.20	48	37.43	34.12	3.31	8.85	....
Average.	....	....	....	....	....	....	....	....	8.99	....

[1] Gain.

NOTE.—Percentages similarly marked (*a*, *b*, *c*, *d*) are the results of measurements in the same section.

It may be noted that the results of measurements tabulated for the season of 1900 give an average loss of 9.87 per cent in the 7,600-foot section of the Logan and Richmond Canal, and, leaving out of consideration the irregular result of July 12, there is an average loss of 9.82 per cent in the 7,180-foot section of Logan, Hyde Park, and Smithfield Canal. There is no diversion of water in the 7,180-foot section of the latter-named canal, and only the small lateral above referred to taking water from the Logan and Richmond Canal. The water carried by this lateral was carefully measured as above described. Therefore the results of the work for the season of 1900 represent the losses in the two canals between the points of diversion and the irrigated lands, and are applicable to those portions of the canal only.

All results given for 1899 are based upon measurements in different sections of the canals adjacent to the irrigated lands. The work done on the Logan and Richmond Canal was in the 41,000 feet following the 7,600-foot section studied during 1900. The work on the Logan, Hyde Park, and Smithfield Canal was confined to the 36,900 feet following the 7,180-foot section studied in 1900. The conditions were such that the losses in those long sections could not be determined by single measurements, and it was therefore necessary to measure the losses in different sections separately. To facilitate the work, the Logan and Richmond Canal was divided into seven sections of nearly equal length and the Logan, Hyde Park, and Smithfield Canal into six. In each of these thirteen sections measurements were made in portions which are thought to be representative of the whole section as far as seepage is concerned. In four of the sections, as will be seen, two sets of measurements were made, and in some others the results are made up from the measurements taken in two or more portions of the section on account of the work being interfered with by the diversion of water for irrigation.

For the purpose of comparison and to facilitate computation there is given in the last column of the table the percentage of loss in each 1,000 feet. The mean of all these in the Logan and Richmond Canal is 0.6 per cent of the water entering the several sections and in the Logan, Hyde Park, and Smithfield Canal is 0.73 per cent.

The plan of the division of the water and the location of the lands to be irrigated is such that the diversion for irrigation makes an almost uniform decrease in the volume of water carried by the canal, so that the average volume in all the sections is approximately half of that entering the upper section. Therefore, of the water entering the distribution section the average percentage lost in each 1,000-foot section is one-half of the mean of all the sections, or 0.3 per cent in the Logan and Richmond Canal, and 0.37 per cent in the Logan, Hyde Park, and Smithfield Canal. The length of the distribution section of the Logan and Richmond Canal being 41,000 feet, the total loss is 12.3 per cent of the water entering that part of the canal. The loss in the part of the canal above the irrigated lands has been

shown to be 9.87 per cent of the water entering the headgates, so that the loss in the distribution section is 11.09 per cent of the water entering the headgate. The total loss in the entire Logan and Richmond Canal is, therefore, 20.96 per cent of the water diverted from the river. The length of the distribution section of the Logan, Hyde Park, and Smithfield Canal, as given above, is 36,900 feet, making the loss 13.65 per cent of the water entering that part of the canal. The loss from the canal above this section is 9.82 per cent. The loss in the distribution section is, therefore, 12.31 per cent of the water entering the headgate, making a total loss of 22.13 per cent of the water diverted by the canal. These results are summarized in the following table. In the table the portion of the canal above the irrigated lands is called the upper section; the remainder of the canal is called the lower section.

Summary of losses by seepage and evaporation.

	Logan and Richmond.	Logan, Hyde Park, and Smithfield.
Length of lower section ....feet..	41,000	36,900
Average percentage of water entering each 1,000-foot section lost in the section ....per cent..	.60	.73
Average percentage of water entering lower section lost per 1,000 feet ....per cent..	.30	.37
Percentage of water entering lower section lost in the section.....do...	12.30	13.65
Percentage of supply entering headgate lost in lower section......do....	11.09	12.31
Percentage of supply entering headgate lost in upper section. ... do. ..	9.87	9.82
Percentage of supply entering headgate lost in whole canal..do....	20.96	22.13

In order to make a discussion of this matter of seepage complete some attention must be given to that portion of the loss found in the lower sections of the canals. The water lost before the irrigated lands are reached needs no further consideration, as it is of no benefit to growing crops. But where the irrigated areas are immediately adjacent to the canal, the seepage from the canal may reduce the volume of water which would otherwise be applied. In passing over these lands the writer has noticed that there seems to be but little difference in the water requirements of land which is only 50 feet from the canals and of that which is 1,000 feet away. In the vicinity of levees there are some exceptions to this rule. In one section of the Logan, Hyde Park, and Smithfield Canal, where the seepage loss was found to be considerable, there was noted on the land below and adjacent to the canal a piece of alfalfa almost entirely burned up through need of water. This condition certainly indicated that in that locality at least the seepage water aided irrigation but little. But if not utilized by the vegetation on adjacent lands, what becomes of all of the seepage water? There is but one other solution of the question. It must join the subsurface supply of water, which is to be found usually in gravel at deptns of from 10 to 20 feet below the surface of the ground in the lower portions of the irrigated district and 30 to 60 feet in the more elevated localities. These supplies are utilized for domestic

purposes by means of wells. The rise and fall of water in a number of wells has been carefully measured at regular intervals, and the measurements show rises of as much as 0.9 foot in a single week after the water was turned into the canal, with a continuation of high water during the whole irrigation season.

All of these results can lead to but one conclusion—the seepage from these two canals is practically an entire loss to the irrigators under them.

VOLUME OF WATER USED.

Irrigation from both canals was begun during the first week in June and was continued until the latter part of September. Prior to the irrigation season preparation was made for a careful measurement of the water near the head of both canals. In each a rectangular flume, 16 feet long and the same width as the canal section, was constructed in such a way as to give a uniform current and cross section. At each of these flumes there was placed an automatic registering machine by which the depth of water in the flume was recorded continuously. At each of the flumes a gage was also established, by means of which the depth recorded by the register was checked at each weekly visit to the station. The ratings of the flumes were made by current-meter measurements covering a sufficient number of depths of water to make possible the preparation of a table of discharges for all depths recorded during the irrigation season. Such a table has been prepared for each one-hundredth of a foot in depth between the limits of the greatest and least observed depths. The record of the water registers gives the depths and the tables show the corresponding discharges, and in this way the volume taken into the canal each day has been computed. The results of these computations are given in the following tables:

Daily flow of Logan and Richmond Canal, season of 1900.

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	154.3308	109.7007	125.9663
2	51.9037	147.0251	110.9328	127.2717
3	113.4072	142.3600	103.0344	127.7231
4	122.2974	137.8351	104.4809	129.3234
5	122.2974	139.2708	120.4292	128.6034
6	122.2974	142.5080	126.2516	121.5573
7	122.2974	140.6441	121.2965	118.9824
8	124.9535	162.7516	120.5728	120.3860
9	137.3985	149.3885	119.3037	125.8206
10	144.3867	138.3536	114.1450	127.7035
11	144.7021	142.0458	116.5909	125.7021
12	146.2791	142.5080	118.1445	125.5229
13	146.2791	145.2078	117.8782	128.5803
14	146.2791	145.9637	99.0982	120.6754
15	144.8656	142.5080	121.6839	111.7167
16	141.5761	142.5080	124.5282	106.3962
17	142.5080	140.6441	122.7974	107.4466
18	140.4970	138.7839	141.2085	107.9667
19	136.8068	138.7839	136.5372	108.1536
20	133.0360	140.6441	132.1470	91.3890
21	135.1379	142.0421	123.3314	86.3570
22	141.9898	140.6441	124.8055	91.5099
23	149.1511	140.6441	112.4763	93.9555

Daily flow of Logan and Richmond Canal, season of 1900—Continued.

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
24	136.2791	140.6441	108.0040	91.0715
25	143.6063	140.6441	112.0490	
26	142.2279	140.6441	106.3962	
27	146.4443	122.4405	104.8356	
28	147.1864	138.5252	105.3058	
29	147.1864	134.0846	111.2227	
30	149.1473	119.9245	124.5270	
31		107.0426	124.8067	
Total	3,922.4246	4,341.3449	3,638.5218	2,749.7811

Duty of water under Logan and Richmond Canal, 1900.

	June (29 days).	July.	August.	September (24 days).	Total (115 days).
Area irrigated ... acres	2,910	3,040	2,990	2,540	3,040
Water used ... acre-feet	3,922.4246	4,341.3449	3,638.5218	2,749.7811	14,652.0724
Depth of water used in irrigation ... feet	1.35	1.43	1.22	1.08	4.82
Loss by seepage and evaporation, 20.96 per cent ... foot	.28	.30	.26	.23	1.01
Depth of water received from irrigation ... feet	1.07	1.13	.96	.85	3.81
Rainfall ... foot	.02	.04	.06	.08	.20
Total depth of water received by land ... feet	1.09	1.17	1.02	.93	4.01
Average flow of canal at head, cubic feet per second	68.17	70.58	59.15	57.96	64.26
Area irrigated per cubic foot per second ... acres	42.68	43.07	50.55	43.82	47.31

Daily flow of Logan, Hyde Park, and Smithfield Canal, season of 1900.

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	83.2340	105.8492	108.4768	81.7291
2	101.6820	99.3634	107.7090	82.8192
3	101.6076	98.3992	106.7559	82.1667
4	102.8803	101.9259	107.8072	83.1648
5	102.0125	102.4120	107.5758	83.0774
6	102.5420	104.8088	105.9973	82.5026
7	98.2105	106.0485	105.9973	82.4068
8	99.1068	110.8188	105.9973	82.4068
9	99.1249	109.3724	104.5510	82.4068
10	93.3626	109.3312	103.6820	81.8192
11	91.6054	109.3312	100.1704	82.1667
12	92.9923	108.8501	100.1704	82.1667
13	94.5972	104.1129	100.1704	81.7770
14	91.8665	105.1880	96.5255	81.3037
15	83.9042	103.8336	85.7896	80.4890
16	87.9027	101.2500	85.7896	81.0644
17	101.6657	103.6765	85.7896	81.0644
18	101.1308	109.1500	85.1944	81.0644
19	96.3635	112.1628	85.4920	81.3039
20	103.8462	108.9491	85.4920	81.6392
21	99.5307	109.3508	85.1944	81.6392
22	104.8996	109.3508	85.1944	81.6392
23	107.5922	110.6353	85.1944	80.3452
24	103.0269	111.5528	85.1944	78.1880
25	103.6848	109.2169	85.1944	78.1880
26	107.0000	109.2169	85.1216	78.1880
27	105.6187	107.0000	84.9760	77.4610
28	103.1228	107.0000	84.3808	
29	112.2136	107.8334	82.6667	
30	113.1392	107.0400	82.2770	
31		107.0000	80.9896	
Total	2,989.5571	3,308.3515	2,901.6072	2,194.1874

Duty of water under Logan, Hyde Park, and Smithfield Canal, 1900.

	June.	July.	August.	September (27 days).	Total (119 days).
Area irrigated .... acres..	2,430	2,890	2,640	2,140	2,890
Water used .... acre-feet..	2,989.5571	3,308.3515	2,901.6072	2,194.1874	11,392.7032
Depth of water used in irrigation . feet..	1.23	1.14	1.10	1.03	3.94
Loss by seepage and evaporation, 22.13 per cent .... foot..	.27	.25	.24	.23	.87
Depth of water received from irrigation .... foot..	.96	.89	.86	.80	3.07
Rainfall .... do....	.02	.04	.06	.08	.20
Total depth of water received by land .... feet..	.98	.93	.92	.88	3.27
Average flow of canal at head, cubic feet per second	50.22	53.79	47.17	40.96	48.26
Area irrigated per cubic foot per second .... acres..	48.39	53.73	55.97	52.25	59.88

No means were available for measuring the water wasted during irrigation. Under the Logan and Richmond Canal the waste amounts to considerable, but in the other canal much greater care is taken in this regard.

The periods of irrigation for the different crops were not determined over the whole area irrigated by the two canals, but information relative thereto was obtained from 25 representative farms.

The results are summarized below:

Irrigation season, 1900.

Crop.	Period of irrigation.	Number of irrigations.	Interval between irrigation, days.
Wheat	June 1 to Aug. 15 ..	2	21
Oats	June 15 to Aug. 20 .	2	25
Alfalfa	June 6 to Sept. 10..	3 to 5	21
Potatoes	July 10 to Aug. 29..	4 to 6	20
Sugar beets	June 15 to Sept. 20.	5 to 7	15
Orchards and gardens	June 1 to Sept. 15 ..	7 to 15	7

About one-half of the entire area produced alfalfa, one-fourth wheat, and the remainder the other crops mentioned above, together with a small quantity of hay, which is irrigated usually but once, early in the season.

It may be noted from the tables that the duty obtained under the Logan, Hyde Park, and Smithfield Canal is considerably greater than that under the Logan and Richmond Canal, in spite of the fact that the demand for water under the former is greater than that under the latter. The crops and the areas devoted to each are about the same under both canals. There are two reasons for this great difference. First, water is less plentiful in the upper canal than in the Logan and Richmond Canal, and, second, the method of distribution, on the time

basis, in use on the upper canal results in considerable care on the part of the irrigator to give the land only the volume of water needed, while the method of distribution on the Logan and Richmond Canal, on the basis of acreage irrigated, generally leads to the application of all the water that can be put onto the land and much less care in the prevention of waste.

When the duty for the different months is considered in connection with the results given above relative to the crops and periods of irrigation, some of the differences are readily explained. It is noted that in both canals the greatest duty was obtained in August, due entirely to the fact that the limited supply of water in the river during that month necessitated greater care in the distribution. The results for July probably show nearer than any other month the average duty of water. In that month there was an abundance of water in the river, all classes of crops were irrigated, and the supply of water in the canals was usually equal to all demands made by irrigators.

Investigations were made during the summer of 1900 in the irrigation of wheat and oats on 12 plats of the Utah Experiment Station farm, which receives its water supply from the Logan, Hyde Park, and Smithfield Canal. Very careful weir measurements were made of all water applied to the different plats, and by the use of a flume from the weir to the plats all waste in application was prevented, so that the results probably indicate the highest duty that can be obtained from the water in the irrigation of these two crops.

The three main objects sought in the experiment were the duty of water, the effect of the application of different volumes, and the effect of different numbers of irrigations during the season. In all of the plats the conditions were made as nearly uniform as possible. The land consists of about 8 inches of light, somewhat sandy loam, 20 inches of ordinary light clay loam, over a bed of coarse gravel of indefinite depth. The method of application in all cases was by flooding and considerable care was taken to apply the water at a uniform depth over the entire plat, and the uniform growth and yield of the plants indicated that the work in that direction was quite successful. The yield of the oats is fully up to the average obtained on farms in this locality, but the wheat crop is considerably below the average, on account of the large number of weeds which grew among it. The results of this investigation are given in the table which follows.

Irrigation of wheat and oats.

Number of plat.	Area of plat.	Crop.	Duration of experiment.	Water applied.		Rainfall.[1]	Total depth water received by land.	Yield per acre.
				Date.	Depth.			
	Acre.		*Days.*		*Foot.*	*Foot.*	*Feet.*	*Bushels.*
1	0.0500	Oats	125	June 18	0.4475	0.5725	1.0200	45.6
2	.0500	do	125	June 19 July 9	.4666 .4866	.5725	1.5257	43.7
3	.0500	do	130	June 18 July 9	.5800 .4608	.5725	1.6133	62.5
4	.0500	do	125	June 20 July 10 July 23	.5000 .5383 .3600	.5725	1.9708	45.6
5	.0500	do	130	June 19 July 10 July 23 July 30	.4525 .4083 .3775 .3200	.5725	2.1308	48.1
6	.0500	do	130	June 20 July 10 July 25 July 30	.8350 .8316 .4800 .5500	.5725	3.2691	62.5
7	.0625	Wheat	125	June 15	.6300	.5725	1.2025	16.5
8	.0625	do	125	June 16 July 9	.8000 .6558	.5725	2.0283	32
9	.0625	do	125	June 16 July 9 July 23	.6108 .6500 .4008	.5725	2.2341	8.8
10	.0625	do	125	June 18 July 10 July 23 July 30	.8508 .5083 .4641 .4400	.5725	2.8357	18
11	.0625	do	125	June 18 July 10 July 23	.5683 .5100 .4370	.5725	2.0878	13.8
12	.0625	do	125	June 19 July 11 July 25 July 30	.6200 .5808 .3700 .3800	.5725	2.5233	16

[1] From planting to harvesting.

Plats 3 and 8 received two irrigations, with an interval of about twenty-one days between them, which is the usual practice among the farmers of the locality. It is noticed, too, that these plats gave very good results, leading to the conclusion that the two irrigations three weeks apart give as good, if not better, results than a greater number of irrigations at shorter intervals. When the mean depth of water on plats 3 and 8, 1.25 feet, is compared with the depth supplied for the whole canal, 3.07 feet, there appears to be a great loss in application by the farmers. But in order that a safe comparison be made there should be a careful determination of the duty of water for alfalfa. The crop is grown on nearly one-half the irrigated area and it requires a much greater amount of water than either wheat or oats. The results given in the table showing the length of the irrigating season and the number of irrigations indicate that an average of four irrigations is necessary for the growth of alfalfa, while wheat and oats receive but two. On this basis the alfalfa requires about double the water needed by those crops, or a depth, when compared with the wheat crop on plat 8, of 2.90 feet, so that the loss is no more than would be expected.

NEBRASKA.

IRRIGATION UNDER THE GREAT EASTERN CANAL, PLATTE COUNTY, NEBR., 1900.

By O. V. P. Stout,

Professor of Civil Engineering, University of Nebraska.

INTRODUCTION.

The Great Eastern Canal is located in the State of Nebraska, principally in Platte County, about 100 miles west and a little north of Omaha. In connection with irrigation investigations the operations under this canal are of especial interest on account of its being situated farther east than any other irrigation canal of considerable size or pretensions anywhere in the arid or semiarid regions of the United States. It can not be claimed that irrigation is here an absolute necessity, since numerous instances abound in the immediate locality of men who have acquired competencies through a few years' practice of agriculture without irrigation. In fact the canal is located in a part of the State where complete failure of crops is rarely known; perhaps it is safe to say that such a thing has occurred not more than twice since the settlement of the country was first undertaken, before the Union Pacific Railroad was constructed. The points then to be noted in connection with the operations under the canal are whether the practice of irrigation can be shown to be a paying expedient; whether the increased returns will pay, or can be depended upon to pay, for the additional expenditure of time or labor and money necessary to raise a crop under irrigation.

From the standpoint of the prospective investor it is interesting and profitable to note the progress of an enterprise such as a canal built in a country where the burden of proof rested on it to demonstrate its usefulness. The Great Eastern Canal was constructed in a locality which was completely settled, many of the farmers resident under the canal being among the earliest pioneers of the State.

A record of precipitation has been kept for a period of thirty years by George S. Truman on section 5, T. 17 N., R. 3 W. This point is about a mile north of the line of the canal and is almost directly opposite the location of the register to which reference is made here-

after. The normal precipitation in inches, as computed by the Weather Bureau from this record, is as follows:

Normal precipitation, Platte County, Nebr.

	Inches.
January	0.79
February	.77
March	1.35
April	3.10
May	4.04
June	4.26
July	3.65
August	3.09
September	2.96
October	1.49
November	.72
December	.87
Total	27.09

From the generally considerable amount and favorable distribution of the precipitation, as above recorded, it is evident that a statement as to the necessity of irrigation will not meet with universal accord. In order that a canal enterprise may be a financial success time must be given for a demonstration to the prospective users of water of the fact, if it be a fact, that the artificial application of water in agriculture in that particular locality will pay.

The common assumption in respect to the eastern boundary of the semiarid region, or the western boundary of the subhumid region, is that it coincides with the one hundredth meridian of longitude. The Great Eastern Canal lies between the ninety-seventh and the ninety-eighth meridians, thus being situated well within the limits of what has been designated as the subhumid region.

The progress of the canal in question in demonstrating its usefulness is set forth in the following statement relative to the acreage irrigated and the number of irrigators for each of the several seasons that it has been in operation:

Progress of irrigation under the Great Eastern Canal.

	1897.	1898.	1899.	1900.
Total area irrigated ......acres	356	671	1,340	2,410
Total number of irrigators	5	21	43	60

It will be noted that the acreage irrigated each year since the beginning has been approximately double that of the preceding year.

Mr. H. E. Babcock, the original promoter and present manager of the canal, has furnished the following general statement:

The irrigating has been very imperfectly done, in the main, but it may be stated as a general average that crops have been increased more than 50 per cent during good years. The average yield of corn has been about 55 bushels per acre where

irrigated, and not to exceed 30 bushels where not irrigated. As high as 90 bushels per acre have been grown, and in one instance 51 bushels of wheat per. acre. Potatoes have not exceeded 250 bushels per acre except in rare instances. Melons have yielded 800 pounds per acre, seed, and Hubbard squash about 200 pounds per acre. In one instance 1 acre of apple trees yielded over $200 net in one season. Sugar beets have reached a maximum at 16 tons per acre, with very high percentage of sugar and in purity.

The irrigation idea is g owing among the patrons. There has been no serious set back, and it is be'ieved that progress will be much more rapid in the future than in the past.

The reports which have been received from irrigators indicate that irrigated corn yielded from 40 to 66 bushels per acre, while 40 bushels per acre was probably about the maximum for that which was not irrigated. In one instance, in which adjoining fields belong to the same man, the yields were: Corn, listed and irrigated, 66 bushels per acre; corn, checked and not irrigated, 20 bushels per acre.

The precise location of the line of the canal, together with the amount and disposition of the land which lies thereunder, are shown by the accompanying map. (Fig. 19.) Up to the present time the entire supply of water has been drawn from Beaver Creek, at the point shown, just south of the town of Genoa. Substantial and costly headgates have been constructed, however, on the north bank of Loup River

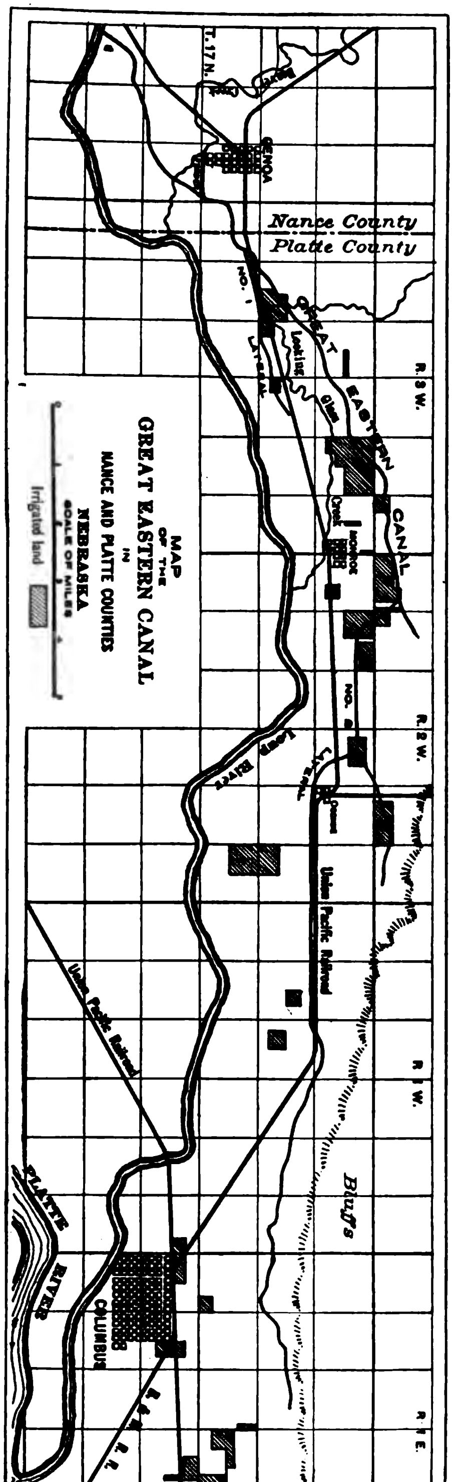


FIG. 19.—Map of Great Eastern Canal, Nebraska.

at the point shown in section 27, nearly 3 miles southwest from Genoa. The company controlling the canal has acquired the right to the use of a continuous flow of 1,200 cubic feet per second from Loup River, and this will be available for use as soon as the connection between the river headgates and the portion of the canal on the east side of Beaver Creek, which at present is only partially constructed, is completed. Beaver Creek has been gaged at various times in the vicinity of Genoa with the following results.

Discharge of Beaver Creek.

	Cubic feet per second.
September 7, 1894	71
July 14, 1896	110
August 14, 1896	112
June 21, 1898	150
August 8, 1900	50

It will be noted that until 1900 there was no observed instance of the flow of the creek falling as low as 50 cubic feet per second. The fact that it fell as low as it did in 1900 was the cause of considerable anxiety to the management of the canal, and of some inconvenience to the users of water. It will probably be found that this fact has served as an incentive to the hastening of the completion of the connection between the Loup River headgates and the portion of the canal which is already constructed.

The map shows also the location of the lands irrigated from the canal during the season of 1900. Points worthy of note are: That the first 5 miles of operated canal served almost entirely as a diversion line, although no physical or topographical obstacles prevent the use of water on the land at points a very short distance below the headgates; also that there is practically no irrigation between Columbus and the point where the canal crosses the railroad, about 5 miles northwest of Columbus. This is explained by the fact that the bed of Lost Creek is used as a channel from that point to a point almost directly north of Columbus, and that the channel throughout this stretch does not invite diversions.

MEASUREMENTS OF WATER USED.

A register was installed in the flume which carries the canal across Looking Glass Creek in section 8, T. 17 N., R. 3 W. (Pl. XV, fig. 1.) The records which have been obtained have been subject to interruptions from various causes, chief of which was the unreliable working of part of the apparatus. The rating of the flume is believed to be fairly reliable, although it presents the peculiarity of a diminished mean velocity accompanying increased depth in the flume. A seemingly satisfactory explanation of this peculiarity lies in the existence of a considerable constriction in the channel of the canal at a short distance—about 150 to 200 yards—below the flume. This caused the

FIG. 1.—LOOKING-GLASS FLUME, GREAT EASTERN CANAL.

FIG. 2.—MEASURING FLUME FOR LATERAL ON SEED FARM OF WESTERN SEED AND IRRIGATION COMPANY.

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water at the higher stages to be held back, and in portions where the channel was of full width, as in the flume, the mean velocity of the flowing water was less than it was at lower stages.

The water was all applied somewhere on the 2,410 acres of which we have record. Of the 2,410 acres, 155 acres were watered by diversion from the canal at points above the place where the register was set. It should be computed, therefore, that the measured water was applied to 2,255 acres.

The flow was first recorded July 14, and no records were obtained after August 17. Even during this period the record was subject to a number of interruptions, the periods of continuous record being as follows: July 14, 9 a. m., to July 20, 6 p. m.; July 21, 4 p. m., to July 25, 2 p. m.; August 4, 9 a. m., to August 10, 8 p. m.; August 14, 6 p. m., to August 16, 6 p. m., and midnight to 10 a. m. on August 17.

The extremes of the period noted above embrace a total of 817 hours, distributed as follows:

Time during which flow of canal was recorded.

Day.	Hour.	Recorded hours.	Unrecorded hours.
July 14	9 a. m.		
July 20	6 p. m.	153	
July 21	4 p. m.		22
July 25	2 p. m.	94	
August 4	9 a. m.		235
August 10	8 p. m.	155	
August 14	6 p. m.		94
August 16	6 p. m.	48	
August 17	0 a. m.		6
Do.	10 a. m.	10	
Total		460	357

The total flow for the 460 recorded hours was 1,504.38 acre-feet. This was sufficient to cover the reported area of 2,255 acres to a depth of 0.667 foot, or almost precisely 8 inches.

The unrecorded hours constitute 43.7 per cent of the total of 817 hours. The ratio of the unrecorded hours to the recorded hours is 77.6 per cent. If it can be assumed that the average rate of flow for the entire 817 hours was the same as for the 460 recorded hours, then the total flow for 817 hours was 2,672 acre-feet, sufficient to cover the reported acreage to a depth of 1.185 feet, or 14.22 inches.

Through the courtesy of the management of the canal we have been supplied with a statement of the names of irrigators in 1900, together with the location and amount of land irrigated by each. Taking this statement as a basis for further inquiry, letters were addressed to each of the irrigators, inclosing a blank form of statement to be filled out, showing certain particulars in regard to the irrigation operations and the results attained in the way of yield. An examination of the returns on these forms from irrigators failed to show that water was applied to more than 10 per cent of the land outside of the limits of July 1 to August 20.

The period from July 1 to August 20, inclusive, would be a total of 51 days of 24 hours each, or 1,224 hours. Assuming that the average rate of flow through the measuring flume was the same during this period as during the period covered by the actual record secured, the average depth of irrigation over 2,255 acres would be 21.3 inches. The rainfall during July and August, taking the mean of that at Monroe and at Mr. Truman's, was 11.17 inches, making a total of 32.47 inches, or 2.71 feet, of water over the fields. This figure is an average for the entire reported acreage, and further assumes that all of the water that passed through the flume reached the fields. No measurements or observations have been made on this canal, so far as known, to determine the rate of loss by seepage or evaporation from canal, consequently there can be no estimate made of the amount by which the water actually applied to the fields differs from that which passed through the measuring flume.

OBSERVATIONS ON THE FARM OF THE WESTERN SEED AND IRRIGATION COMPANY.

The tracts selected for this purpose are situated in the north half of section 2, T. 17 N., R. 3 W. of the sixth principal meridian, about

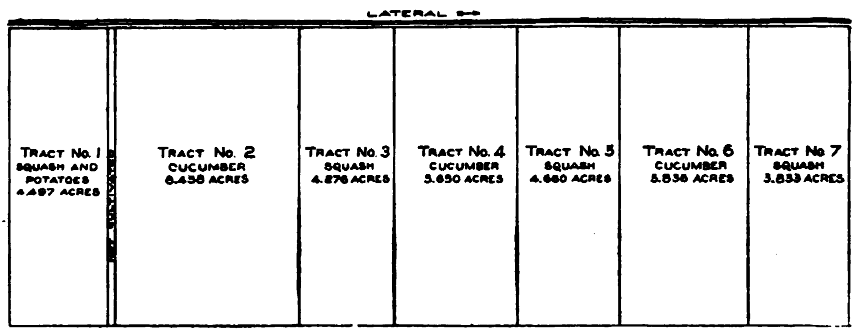


FIG. 20.—Irrigated tracts on farm of Western Seed and Irrigation Company, near Monroe, Nebr.

1¾ miles west of Monroe, Nebr. They were planted mostly to squash and cucumbers, the exceptions being potatoes, which were planted with one patch of squash, and 3 acres of onions. The lateral which leads from the Great Eastern Canal to these tracts has a good fall. The measurement of the water used was accomplished by means of a flume (Pl. XV, fig. 2), which was placed for that purpose in the lateral at a point about 150 yards from the edge of the field. The accompanying sketch (fig. 20) shows the relative location of the different crops, together with the acreage of each. The lateral ran along the north side of the field, and, in irrigating, the water was checked up so as to run to the south along 21 or 22 rows at once. This gave the water a run of about 250 yards across the field to the south side. It was realized that this distance was too great, and it is expected hereafter to accomplish a saving of time and of water by running another lateral in an easterly direction across the field on a line to the south of the main lateral.

It is believed that the measurements of quantity of water applied were reasonably accurate in this case, and that the results may be accepted as setting forth truly the practice of that irrigator for the season of 1900. It is to be regretted, however, that unprecedentedly heavy rains during the second week in September submerged the fields and injured the crops to a decided extent. Mr. George Emerson, the manager of the farm, has stated that in his opinion this flooding of the fields reduced the yield of the crop nearly or quite 50 per cent. It must be plain, therefore, that whatever effect the irrigation may have had on the yield was obliterated by this later occurrence. The flood and not the artificially applied water had the preponderating effect.

The farm of which these tracts are a part is one which has been in part redeemed from a swamp, so that it might be assumed that even without irrigation a distressing need of water for crops would rarely be felt.

The field has a pronounced, but not a steep, slope to the south and the east. The water runs over the field readily in either of these directions, and at the same time the slope is so gentle as to cause no difficulty from the washing of the soil.

For convenience of reference the tracts have been numbered in their order from west to east, as shown on the sketch. The following tabulations set forth the data necessary to determine the duty of the water applied to the several tracts:

Tract No. 1.

	Irrigations.		
	First.	Second.	Total.
Date of irrigation	July 1	July 10	....
Duration of irrigation ... hours	10	5	15
Area irrigated ... acres	4.50	4.50	4.50
Water used ... acre-feet	1.20	1.63	2.83
Depth of water used in irrigation ... foot	.267	.362	.629
Rainfall June 1 to August 10 ... do	....	....	.60
Total depth of water received during growth ... feet	....	....	1.229
Average head of water used ... cubic feet per second	1.45	3.94	....
Total yield of squash seed ... pounds	....	....	1,213
Yield per acre of squash seed ... do	....	....	270

NOTE.—A crop of potatoes grew with the squash on this tract. The yield of the potatoes was not reported.

Tract No. 2.

Date of irrigation	August 6–8
Duration of irrigation ... hours	23
Area irrigated ... acres	8.46
Water used ... acre-feet	4.70
Depth of water used in irrigation ... foot	.556
Rainfall June 1 to August 10 ... do	.60
Total depth of water received during growth ... feet	1.156
Average head of water used ... cubic feet per second	2.47
Total yield of cucumber seed ... pounds	1,681
Yield per acre of cucumber seed ... do	199

Tract No. 3.

	Irrigations.		
	First.	Second.	Total.
Date of irrigation	July 8	Aug. 4	
Duration of irrigation ..... hours	6	8	14
Area irrigated ..... acres	4.28	4.28	4.28
Water used ..... acre-feet	1.38	2.68	4.06
Depth of water used in irrigation ..... foot	.322	.626	.949
Rainfall June 1 to August 10 ..... do			.60
Total depth of water received during growth ..... feet			1.549
Average head of water used ..... cubic feet per second	2.79	4.06	
Total yield of squash seed ..... pounds			1,274
Yield per acre of squash seed ..... do			298

Tract No. 4.

Date of irrigation	August 9
Duration of irrigation ..... hours	8
Area irrigated ..... acres	5.65
Water used ..... acre-feet	1.78
Depth of water used in irrigation ..... foot	.315
Rainfall June 1 to August 10 ..... do	.60
Total depth of water received during growth ..... do	.915
Average head of water used ..... cubic feet per second	2.70
Total yield of cucumber seed ..... pounds	745
Yield per acre of cucumber seed ..... do	132

Tract No. 5.

	Irrigations.		
	First.	Second.	Total.
Date of irrigation	July 8	Aug. 5	
Duration of irrigation ..... hours	10	9	19
Area irrigated ..... acres	4.66	4.66	4.66
Water used ..... acre-feet	2.68	2.85	5.53
Depth of water used in irrigation ..... foot	.575	.612	1.187
Rainfall June 1 to August 10 ..... do			.60
Total depth of water received during growth ..... feet			1.787
Average head of water used ..... cubic feet per second	3.24	3.83	
Total yield of squash seed ..... pounds			290
Yield per acre of squash seed ..... do			62

Tract No. 6.

Date of irrigation	August 10
Duration of irrigation ..... hours	20
Area irrigated ..... acres	5.84
Water used ..... acre-feet	4.77
Depth of water used in irrigation ..... foot	.817
Rainfall June 1 to August 10 ..... do	.60
Total depth of water received during growth ..... do	1.417
Average head of water used ..... cubic feet per second	2.89
Total yield of cucumber seed ..... pounds	800
Yield per acre of cucumber seed ..... do	137

Tract No. 7.

	Irrigations.		
	First.	Second.	Total.
Date of irrigation	July 7	Aug. 9	....
Duration of irrigation ... hours	10	10	20
Area irrigated ... acres	3.83	3.83	3.83
Water used ... acre-feet	2.68	3.17	5.85
Depth of water used in irrigation ... foot	.700	.828	1.528
Rainfall June 1 to Aug. 10 ... do	....	....	.60
Total depth of water received during growth ... feet	....	....	2.128
Average head of water used ... cubic feet per second	3.24	3.83	....
Total yield of squash seed ... pounds	....	....	1,000
Yield per acre of squash seed ... do	....	....	261

Tract No. 8.

	Irrigations.		
	First.	Second.	Total.
Date of irrigation	July 6	Aug. 11	....
Duration of irrigation ... hours	6	10	16
Area irrigated ... acres	3	3	3
Water used ... acre-feet	1.61	3.11	4.72
Depth of water used in irrigation ... foot	.537	1.037	1.574
Rainfall June 1 to Aug. 10 ... do	....	....	.60
Total depth of water received during growth ... feet	....	....	2.174
Average head of water used ... cubic feet per second	3.24	3.77	....
Total yield of squash seed ... pounds	....	....	767
Yield per acre of squash seed ... do	....	....	256

Tract No. 9.

	Irrigations.		
	First.	Second.	Total.
Date of irrigation	July 7	Aug. 3	....
Duration of irrigation ... hours	8	10	18
Area irrigated ... acres	3	3	3
Water used ... acre-feet	2.14	3.11	5.25
Depth of water used in irrigation ... foot	.713	1.037	1.75
Rainfall June 1 to Aug. 10 ... do	....	....	.60
Total depth of water received during growth ... feet	....	....	2.35
Average head of water used ... cubic feet per second	3.24	3.77	....
Total yield of onions ... bushels	....	....	125
Yield per acre of onions ... do	....	....	42

There is but little to be noted in the way of additional analysis of the figures set forth in the foregoing tables. It may be noted that as a general rule the quantity of water used for a single irrigation becomes larger the greater the distance of the field from the head of the lateral. Of course it can be taken for granted that there is a certain and perhaps material loss of water in the passage through the lateral from the canal to the field, but the fact that for the fields farthest down the lateral water was supplied to about 60 per cent in excess of that which was furnished to the fields in which the water

flowed a less distance in reaching can not be completely accounted for by any reasonable assumption as to loss of water by seepage from the lateral in the intervening distance of something less tnan half a mile. The lateral was permitted to overflow its banks on the north side to a seemingly small extent, and the water stood in pools in a road or trail which ran along the north side of the field. This fact will serve to explain at least a small part of the difference in the duty of water on the upper and lower tracts. The results on tracts Nos. 8 and 9 should not be given full weight in this or other connections, since the areas of these tracts were not precisely measured.

The growing of seed crops under this canal should be watched with interest, since it has been frequently stated, in considering the advisability of constructing works for irrigation in the subhumid region, that if irrigation is to be made a success in that region it must be through paying increased attention to special crops, but that the ordinary field crops could not be grown at a profit when they must meet in the market the products of dry farming. It was admitted that in years of insufficient or unfavorably distributed rainfall the irrigator might have a crop while his neighbor on the dry farm would be without one. Among the special crops which have been suggested are seed crops, sugar beets, orchards, small fruits, etc. For the ordinary field crops it has been considered by many that irrigation can not be looked upon as more than an insurance, and that a man can afford to pay but little more to irrigate a crop than he can pay for insurance.

OBSERVATIONS ON FARM SOUTH OF OCONEE, NEBR.

The farm consists of the northeast quarter of section 14, in the same township as Oconee. (Fig. 21.) It is the property of Mr. H. E. Babcock, the manager of the canal. The soil is of a very light, sandy character, and in appearance does not seem to invite agricultural use. So sandy, indeed, is the land that the place is known as the "sand-hill farm." Water from the canal has been applied with a double purpose in view. In addition to furnishing the moisture which may be required for the growth of crops, it has been considered that the fertilizing elements in the water would enrich the soil, and with that idea in mind the use of water has not been limited to that which might be necessary for the use of the crop which was on the ground at the time. The distance to ground water is about 4½ feet.

Water is led to the farm from the canal in a lateral which has been excavated in the crown of an abandoned railroad embankment, which affords the best command of the land to be irrigated. This is a fortunate fact, for the ground is very humpy, and a low-level lateral might necessitate a considerable amount of work on the fields in order that the water might reach them from the lateral.

A measuring flume has been placed in the lateral at a point about

FIG. 1.—MEASURING FLUME, NEAR OCONEE, NEBR.

FIG. 2.—MEASURING FLUME, NEAR OCONEE, NEBR.

FIG. 3.—CORNFIELD NEAR CULBERTSON, NEBR., SHOWING DESTRUCTION WROUGHT BY GRASSHOPPERS.

300 yards above the north line of the farm, and the estimate of the amount of water used is based on the record of depth in this flume. The first recorded irrigation was on June 27, although some water had been used before the measuring flume was put in place. The record of the total amount of water used is believed to be reasonably accurate. The record of distribution is in general correct, but is not as accurate as the record of total amount used, owing principally to

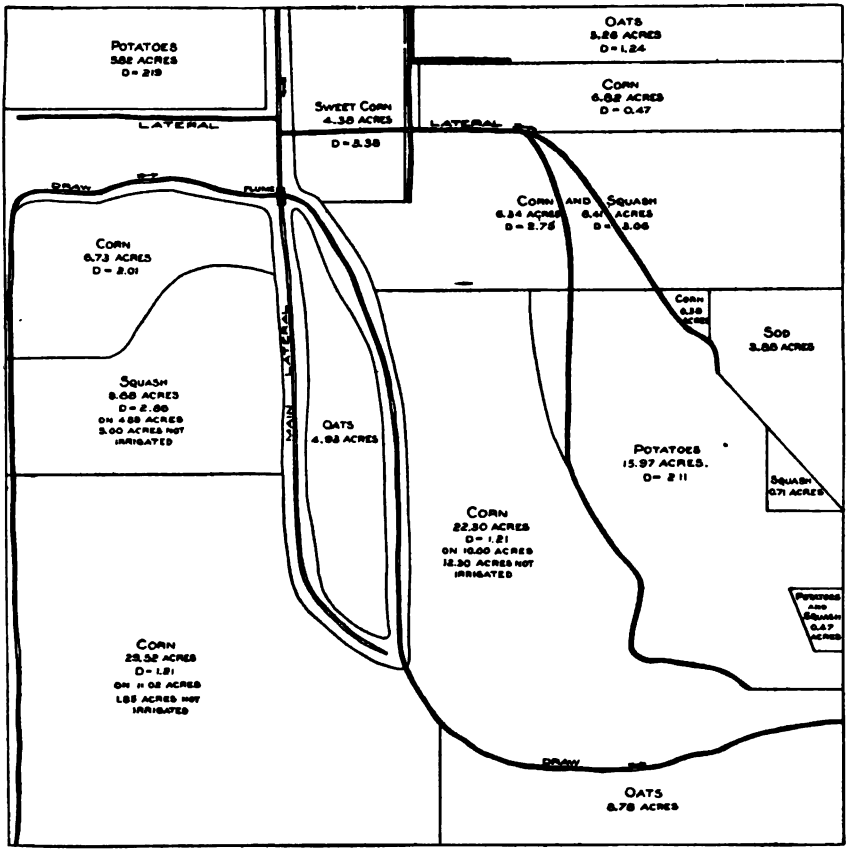


FIG. 21.—Plat of farm of H. E. Babcock, near Oconee, Nebr.

the irregular shapes and distribution of the fields. The irrigation of crops ceased on August 15.

Potatoes.—Potatoes were grown in two different fields. One, having an area of 5.82 acres, was immediately adjacent to the main lateral. It was irrigated June 28–30 and August 11–12, the latter irrigation being more copious. The total depth of water applied was 2.19 feet. The yield was 82½ bushels per acre. The water traveled nearly 2,000 feet in a farm lateral to reach the more remote portions of the other field. Its area was 15.97 acres. It was irrigated scantily or in part July 28–31, copiously August 1–5, and scantily August 15. The total

depth applied was 2.11 feet, and the yield was 84 bushels per acre. The potatoes were worth 50 cents per bushel.

Squash.—Squash were planted in two fields. In one of the fields a few rows of squash alternated with a few rows of sweet corn in such proportion that about one-third of the field, or 5 acres, has been noted as squash. Another field of 4.88 acres was squash alone. Irrigations, in whole or in part, were made at intervals from June 29 to August 14. The depth on that portion of the first field which was nearer to the main lateral, amounting to about 40 per cent of the entire field, was 2.75 feet. On the remainder of the field it was 3.06 feet. The depth on the field of squash alone was 2.86 feet. The yield of irrigated squash was 113 pounds of seed per acre. A 5-acre field of squash which was not irrigated yielded 56 pounds of seed per acre. The seed was worth 15 cents per pound. Forty loads of rinds were sold at the farm for 60 cents per load, and about ten loads were used on the farm.

Sweet corn.—The irrigated sweet corn comprised a total of 48.70 acres, in six separate fields. It was irrigated, each time in part, at intervals throughout the period of record. The depths of water applied were 1.21 feet on 21.01 acres, 2.01 feet on 6.73 acres, 3.38 feet on 4.38 acres, 2.75 feet on 4.20 acres, 3.06 feet on 5.55 acres, 0.47 foot on 6.82 acres. The yield of irrigated sweet corn was 15.2 bushels of seed corn per acre. The yield was cut down materially by damage which hogs did to about 10 acres. The fields of sweet corn not irrigated amounted to 30.82 acres and yielded 181 bushels, or a little less than 6 bushels of seed per acre. The seed corn was worth 80 cents per bushel.

Oats.—A field of oats containing 5.26 acres was covered to a depth of 1.24 feet, but no record was kept of the yield.

During the period of record 171 acre-feet was applied to an area of 86.81 acres, corresponding to an average depth of 1.97 feet over the ground. No record of natural precipitation was kept at a point nearer than 5 miles from the farm. The total for June, July, and August was 1.09 feet. The total from June 1 to August 20 was 0.91 foot. It thus appears that the crops during the period of growth obtained their moisture from an amount of water corresponding to an average depth of about 2.88 feet over the irrigated area.

No conclusions can be drawn as to the improvement of this sandy soil by the application of water from the first year's work. Observations along that line will be watched with interest.

WYOMING.

THE USE OF WATER FOR IRRIGATION AT WHEATLAND, WYO.

By C. T. Johnston.

Assistant in Irrigation Investigations.

The investigations carried on in 1899 at Wheatland were continued in much the same way during 1900. A continuous record has been kept of the discharge of Canal No. 2, and in this way the general duty of water thereunder has been found. Special measurements were carried on to determine the volume necessary for growing potatoes and oats. The season of 1900 was much more favorable as far as the water supply is concerned than that of 1899. The reservoir above Canal No. 2 was filled during the spring months, and its supply was not drawn upon until early in July.

The measuring station on Canal No. 2 was maintained at the sand gate, a quarter of a mile below the headgate. Additional gagings were made of the discharge of the canal there to check the rating table prepared in 1899. There is no irrigated land above this point, and the record kept indicates what is supplied for all of the land under the canal.

The results of the season of 1899[1] showed that there is a great difference between the net and gross duty of water under the canal. For instance, only 0.7 acre-foot per acre was needed for the irrigation of corn, while the average depth of water under the canal was over 2.5 feet. Of course there is more water used for the irrigation of alfalfa, timothy, natural hay, and other crops than is necessary for corn. Yet it is very doubtful whether any of these crops used a volume as great as that obtained from the measurement of the general duty of water under the canal. The only way to account for this difference is to ascribe it to the water lost from the canal and laterals through seepage and evaporation. In planning the work for the season of 1900 it was desired to determine as closely as possible the actual losses due to these two causes.

EVAPORATION MEASUREMENTS.

It is a comparatively easy task to install an evaporation tank and measure each week the depth of water lost through evaporation. Whether the results obtained in this way apply to the volume lost

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

from reservoir and canal surfaces is doubtful. Evaporation is greater in windy weather than when the air is quiet. It is greater from streams having riffles and falls than from those in which the water runs without such disturbances. Reservoirs having considerable depth lose less water, other things being equal, than shallow ones. This is largely due to the fact that cold water settles to the bottom of deep reservoirs, and in this way keeps the entire body at a lower temperature. All of the conditions surrounding water standing in reservoirs and running in canals can not be obtained in the evaporation tank. It is a difficult matter to determine even approximately the evaporation from the surfaces of large bodies of water, and all that can be done is to come as near to the truth as possible.

To find roughly the difference in the rate of evaporation from the surface of water running in a canal and from the water of an evaporation tank, two records were kept during the season of 1900 at Wheatland. An evaporation tank was placed in the ground in the usual manner. Another tank of similar dimensions was placed in Canal No. 2. The latter tank was supported on a raft which was anchored to the banks. All precautions were taken in both cases to prevent water being lost through any other source than evaporation, and it is believed that the results of the test are quite accurate. The table given below shows the depths lost during each week from June 2 to October 16. The greatest loss occurred during July, the total evaporation during that month being 19.33 inches from the tank on land and 16.72 inches from the tank in the water. The table given below shows the evaporation from each tank and the excess of evaporation from the land tank over the one in the water for each week and for the season.

Evaporation at Wheatland, Wyo., 1900.

Date.	Evaporation from tank on land.	Evaporation from tank in water.	Excess from tank on land.	
			Depth.	Percentage.
Week ended—	*Inches.*	*Inches.*	*Inches.*	
June 9	3.50	3	0.50	17
June 16	3.95	3.35	.60	18
June 23	4	3.60	.40	11
June 30	4.28	3.78	.50	13
July 7	4.75	4.25	.50	12
July 14	4 18	3.98	.20	5
July 21	5.59	4.39	1.20	27
July 28	3.98	3.58	.40	11
August 4	3.50	2.60	.90	35
August 11	3.63	2.63	1	38
August 18	3.40	2.60	.80	31
August 25	3.40	2.40	1	42
September 1	3.40	3	.40	13
September 8	3.40	2.20	1.20	55
September 15	2.94	2.44	.50	20
September 22	2.25	1.75	.50	29
September 29	1.98	1.48	.50	34
October 6	2.02	1.67	.35	21
October 13	2 25	1.75	.50	29
Total	66.40	54.45	11.95	22

It is interesting to note that there is always an excess of evaporation from the land tank and that it never exceeded 1.2 inches for any week. Why the difference in loss between the two tanks should vary as much as it does can not be explained. It is probably in a large measure due to the fact that the earth heats more quickly than the water. The evaporation from the tank on land would, under this assumption, be more quickly affected by every change in the temperature than from the tank in the water. It will be noticed that during the time the record was kept 66.4 inches, or 5 feet 6.4 inches of water in depth, was lost from the tank in the ground, and 54.45 inches, or 4 feet 6.45 inches, was lost from the tank in the water. The difference between the losses in depth from the two tanks is therefore about 1 foot.

When it is considered that the water in the canal is constantly moving and is subject to more or less disturbance the loss from its surface will probably more nearly approximate the results from the land-tank measurements. The results obtained from the tank in the water will probably more nearly apply to the loss of water from the reservoir surface. However, it will likely be excessive for anything except quite shallow basins. Although the loss due to evaporation in Wyoming is of comparatively small importance, yet it should be determined in connection with seepage measurements.

Between June 15 and August 31, during which time Canal No. 2 was in operation, 44.75 inches of water was lost from the land tank through evaporation. Applying these figures to the surface of the water in Canal No. 2 during that period the volume lost can be ascertained. The canal is approximately 20 miles long and averages 20 feet wide on the water line. This gives it a surface area of 2,112,000 square feet when the canal runs full. The loss by evaporation is 3.73 feet, and the volume lost, therefore, in cubic feet is 7,877,760, equal to 180.85 acre-feet, or a continuous flow of 1.17 cubic feet per second for the seventy-eight days the canal was in use.

When water is being diverted from the canal the average width of the water surface will, of course, be less than 20 feet, as it varies from a maximum of 24 feet at the headgate to zero at the point where the last of the water is taken from the canal. During low water a plan of rotation is adopted, so that for half the time no water flows in the canal below the town of Wheatland, thus cutting off evaporation from the lower half of the canal. During this same time the canal is not carrying its full capacity even at the head, so that the water surface exposed to the air is considerably less than half of that given above—how much less it is impossible to tell. The 1.17 cubic feet per second given above is, then, the maximum possible loss, with the actual loss running from half that amount down to an indeterminate minimum. This loss becomes so small that it can be disregarded and all loss be charged to seepage.

Below is given a table for computing the evaporation from water surfaces in cubic feet per second when tank measurements have been made:

Evaporation reduction table.

Depth of water evaporated in one week.	Loss from 1,000,000 square feet of water surface.	Depth of water evaporated in one week.	Loss from 1,000,000 square feet of water surface.
Inches.	*Cubic foot per second.*	*Inches.*	*Cubic foot per second.*
1	0.138	2.6	0.358
1.1	.152	2.7	.372
1.2	.165	2.8	.386
1.3	.179	2.9	.400
1.4	.193	3	.413
1.5	.207	3.1	.427
1.6	.221	3.2	.441
1.7	.234	3.3	.455
1.8	.248	3.4	.469
1.9	.562	3.5	.482
2	.276	3.6	.496
2.1	.289	3.7	.510
2.2	.303	3.8	.524
2.3	.317	3.9	.537
2.4	.331	4	.551
2.5	.345		

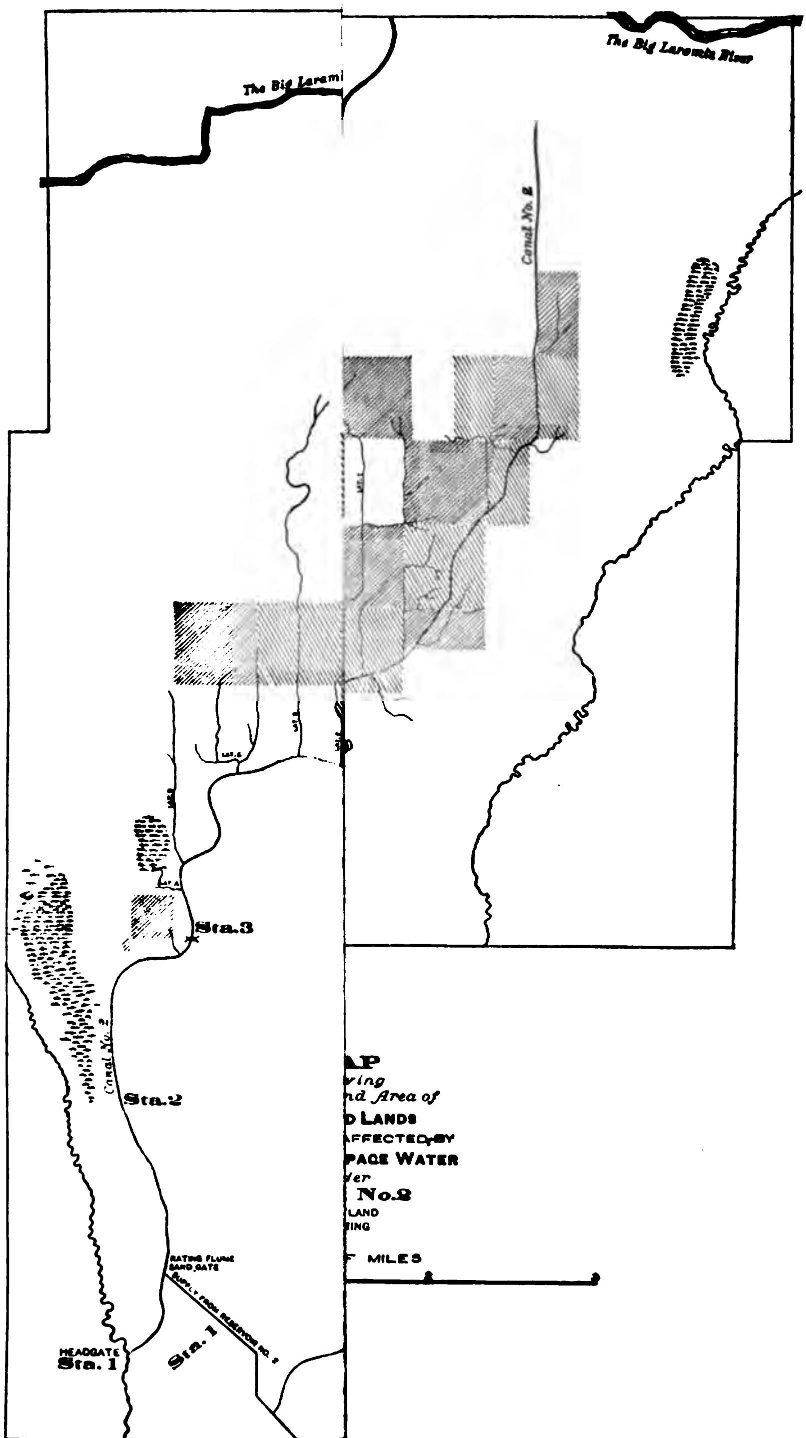
SEEPAGE MEASUREMENTS.

The accompanying table shows the general results of the seepage measurements made on Canal No. 2 during July and August, 1900. The points selected along the canal where gagings have been made have been named Station 1, Station 2, etc., and are indicated on the map (fig. 22). These stations were selected with reference to securing accurate gagings, and an attempt was also made to divide the canal into similar sections relative to soil and other features which might affect the rate of seepage. Station 1 is located on the main canal near its headgate and also on the lateral running from reservoir No. 2.

The first two columns of the table give the stations at the ends of the various sections of the canal. Hence the figures in the same line refer to the sections bounded by these stations. The third column in the table gives the length of each section of the canal measured along the same.

Seepage measurements made on Canal No. 2, Wheatland, Wyo., July 9, 10, 11, 1900.

Place of measurement of canal.		Distance between stations.	Discharge upper station.	Diversions between stations.		Discharge lower station.	Loss.			
Upper station.	Lower station.			Lateral.	Discharge.		Quantity.	Percentage.	Per mile.	
		Miles.	*Cu. ft. per sec.*		*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*		*Cu. ft. per sec.*	*Per ct.*
Station 1	Station 2	1.50	89.65			85.30	4.35	4.85	2.90	3.23
Station 2	Station 3	2.50	85.30			81.07	4.23	4.96	1.70	1.98
Station 3	Station 4	2.40	81.07			78.01	3.06	3.77	1.28	1.57
Station 4	Station 5	4.40	78.01	Lateral J Lateral K Lateral L	22.05 2.05 1.69	49.44	2.78	3.56	.63	.81
Station 5	Station 6	1.70	49.44			49.24	.20	.40	.12	.24
Station 6	Station 7	2.17	49.24	Lateral M Lateral O	1.10 19.78	27.88	.48	.97	.22	.45
Station 7	Station 8	2.33	27.88	Lateral P Lateral S Lateral T	2.70 5.29 4.32	15.42	.15	.53	.06	.22
	Total	17			58.98		15.25	17.01	.90	
	Average									1



The Big Laramie River
Canal No. 2
Sta.3
Sta.2
Canal No. 2
RATING FLUME
SAND GATE
SUPPLY FROM RESERVOIR NO. 2
HEADGATE
Sta. 1
Sta. 1
Area of
LANDS
WATER
No.2
LAND
MILES

Seepage measurements made on Canal No. 2, Wheatland, Wyo., August 20, 21, 22, 1900.

Place of measurement of canal.		Distance between stations.	Discharge upper station.	Diversions between stations.		Discharge lower station.	Loss.			
Upper station.	Lower station.			Lateral.	Discharge.		Quantity.	Percentage.	Per mile.	
		Miles.	*Cu. ft. per sec.*		*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*	*Cu. ft. per sec.*	*Per cent.*
Station 1	Station 2	1.50	36.52	....	....	35.06	1.46	4	0.97	2.67
Station 2	Station 3	1.50	35.06	....	....	34.01	1.05	3	.70	2
Station 3	Station 4	2.40	34.01	C D E	2.60 .86 7.49	23.33	[1].27	[1].79	[1].11	[1].33
Station 4	Station 5	4.40	23.33	H J K L	4.14 6.33 .34 1.24	13.31	[1]2.03	[1]8.01	[1].46	[1]1.82
Station 5	Station 6	1.70	13.31	....	....	12.24	1.07	8.04	.63	4.73
Station 6	Station 7	2.17	12.24	M N O	.19 1.24 4.21	6.41	.19	1.55	.09	.71
Inflow from above		....	....	....	....	....	3.21	....	....	....
Total		13.67	....	....	28.64	....	4.68	12.82	[2].11	....
Average		....	....	....	....	....	....	....	....	[2].29

[1] Gain. [2] Exclusive of inflow from above.

It will be noticed that in the measurements made during July the canal was followed for only 17 miles and in August 13.67 miles. This does not represent the total distance traveled in making gagings, as a number of the laterals were followed and the canal was also inspected from one end to the other, some 40 or 50 miles. Owing to the small discharge below stations 7 and 8 in the two series of measurements, the results were not considered sufficiently accurate to be embodied in the table.

During the period beginning July 9 the canal had a discharge of 89.65 cubic feet per second at its head. At 1.5 miles below the head this was reduced to 85.3 cubic feet per second, and at 1.5 miles farther the discharge was reduced to 81.07 cubic feet per second, as shown in the fourth column. Each lateral taking water from the main canal was measured, and its name is given in the fifth column and its discharge in the sixth column. The discharge of the laterals must be subtracted from the discharge of the canal before the total loss in cubic feet per second can be found. It will be noticed that at Station 5 the discharge of the main canal was 49.44 cubic feet per second. The discharge of laterals J, K, and L was 25.79 cubic feet per second. When this total discharge of the laterals is added to the discharge at station 5 and the sum subtracted from the discharge at station 4, there remains 2.78 cubic feet per second to be accounted for. This volume of water was lost between stations 4 and 5. The loss in each section is given in the eighth column. The percentage of loss and loss per mile are shown in the ninth and tenth columns, respectively. The total discharge of the laterals, the total loss from the canal, etc., are given at the bottom of the table. It will be seen that 66 per cent of the water furnished by the canal at its head was taken out in laterals,

17 per cent was lost through evaporation and seepage, and 17 per cent remained in the canal at station 8. From measurements made on one of the larger laterals, it is probable that 12 to 15 per cent of the water furnished them was lost before it reached the fields.

During the time covered by the measurements in August a considerable volume of water ran into the canal from ditches and fields directly above. In the time intervening between the two measurements a heavy rain occurred at Wheatland, which may have served to silt the channel to some extent and in that way prevent a portion of the seepage. The measurements in August showed a smaller percentage of loss, even when water flowing in from above is taken into consideration. The measurements as taken show that the canal received 36.52 cubic feet of water per second at its headgate; 6.41 cubic feet per second remained in the canal at station 7. The laterals diverted 27.4 cubic feet per second, or 75 per cent of the volume furnished the canal. The water flowing into the canal on the surface from above was measured as carefully as it could be, and showed a discharge of 3.21 cubic feet per second. This should be added to the total loss as given by the eighth column, and raises the figures there given—1.47 cubic feet per second—to 4.68 cubic feet per second. Allowing for this correction, the laterals diverted 69 per cent of the water furnished, 13 per cent was lost, and 18 per cent remained in the canal at station 7.

DUTY OF WATER UNDER CANAL NO. 2, 1900.

The July measurements of seepage show a loss of 17 per cent in the main canal and the August measurements 13 per cent. The measurements on the laterals showed a loss of about 15 per cent. Taking the mean of the two measurements for the loss in the main canal, we have an approximate loss of 30 per cent between the sand gates near the head of the canal and the point of using the water.

The following table shows the discharge of the canal at the sand gates:

Discharge of Canal No. 2, Wyoming Development Company, Wheatland, Wyo., season of 1900.

Day.	June.	July.	August.	Day.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*		*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	506.28	392.16	18	294.96	466.32	266.28
2	....	548 04	392.16	19	294.96	466.32	266.28
3	....	506.28	82 80	20	294.96	266 28	266 28
4	....	466 32	68.64	21	266 28	206.28	266 28
5	....	548.04	82.80	22	266 28	266 28	266.28
6	....	548 04	82 80	23	294.96	757.80	266.28
7	....	506 28	82.80	24	266.28	757.80	266.28
8	....	506 28	68.64	25	239.52	266 28	266 28
9	....	548.04	62 80	26	239 52	266.28	266.28
10	....	548 04	266.28	27	266.28	214.56	266.28
11	....	466.32	214.56	28	325.44	214.56	266.28
12	....	466 32	266.28	29	357.84	214.56	266.28
13	....	392 16	266 28	30	428 28	266.28	266.28
14	....	392.16	294.96	31	....	266.28	266.28
15	239.52	466.32	294.96				
16	266.28	466.32	325.44	Total	4,580.88	13,303.44	7,238.56
17	239.52	466.32	266.28				

In addition to the water furnished by the canal, the crops near Wheatland received 2.88 inches of rainfall during growth. This was distributed as follows:

Monthly precipitation at Wheatland, Wyo., 1900.

	Inches.
June	0.43
July	2.12
August	.33
	2.88

Including the rainfall and deducting 30 per cent for loss by seepage and evaporation, the duty of water under Canal No. 2 was as follows:

Duty of water under Canal No. 2, 1900.

Area irrigated	acres	5,122
Water used	acre-feet	25,122.88
Depth of water used in irrigation	feet	4.90
Loss by seepage and evaporation, 30 per cent	do	1.48
Depth of irrigation	do	3.42
Rainfall, June, July, and August	foot	.24
Total depth of water received by land	feet	3.66

In addition to continuous measurements made of the discharge of Canal No. 2 records were kept during the season to determine the volume of water necessary for irrigating oats and potatoes. Approximate figures were also secured of the volume used for the growth of wheat, alfalfa, and corn. All of the fields in which these products were grown were under the same lateral and the same weir measured the water used to irrigate both oats and potatoes. The accompanying tables show the time when water was needed for irrigation, the period required for each irrigation, the volume of water used, the value of such water, and the value of the total crops harvested:

Oats.

Number of irrigation.	Time water was turned on.	Time water was turned off.	Period.		Volume applied.	Average flow.	Depth to which land was covered.
			Days.	*hrs.*	*Acre-feet.*	*Cu. ft. per sec.*	*Feet.*
First	July 5, 4 a. m.	July 8, 4 p. m	3	12	14.38	2.05	[1] 0.58
Second	July 16, 11 a. m.	July 23, 7 p. m	7	8	28.68	1.97	[2] 1.79
			10	20	43.06		2.37

[1] Twenty-five acres first irrigation. [2] Sixteen acres second irrigation.

Potatoes.

[10 acres.]

Number of irrigation.	Time water was turned on.	Time water was turned off.	Period.		Volume applied.	Average flow.	Depth to which land was covered.
			Days.	*hrs.*	*Acre-feet.*	*Cu. ft. per sec.*	*Feet.*
First	Aug. 2, 7.30 a. m	Aug. 8, 6 a. m	5	22¼	12.36	1.05	1.24
Second	Aug. 17. 8 a. m	Aug. 22, 1 p. m	5	5	10.17	.99	1.02
Third	Aug. 26, 6 p. m	Aug. 30, 2 p. m	4	8	13.70	1.60	1.37
			15	11¼	36.23	....	3.63

It is interesting in this connection to note that oats were watered only in June and were harvested before potatoes were watered the first time. The potatoes were irrigated first, beginning August 2 and were watered three times during that month. Sufficient water was applied to the ground to have covered it to a depth of 3.63 feet. It will be noticed that only 16 of the 25 acres of oats required a second irrigation, hence 9 acres were grown with but 5.22 acre-feet of water, or a volume sufficient to cover the ground to a depth of 0.58 foot. The yield of this field of oats was 30 bushels per acre, or 750 bushels from the 25 acres.

VALUE OF WATER APPLIED.

The total area farmed under Canal No. 2 during 1900 was 5,122 acres; 1,279 acres were devoted to growing wheat. The yield of wheat was 23,164 bushels, which had a market value of $13,898.40. The portion of the entire volume of water supplied by Canal No. 2 which was required for the growth of wheat is approximately 6,052.57 acre-feet. This figure is obtained from the relative duty of water of all the crops grown under Canal No. 2. The value of an acre-foot of water as applied to wheat is therefore only $2.29. If all of this water were applied to the land and no part of it lost in transit it would have covered the ground to a depth of 4.73 feet. The 25-acre field of oats on which measurements were made yielded 750 bushels, the cash value of which was $412.50. The water used on this crop was 43.06 acre-feet, giving a value of $9.58 per acre-foot of water used. The potatoes gave a yield of 800 bushels. These sold for $400, making the value of water applied $11.04 per acre-foot. The following table gives similar figures for all crops raised under canal No. 2. The total value of all crops grown under the canal was $76,796.35. The mean value of an acre-foot of water was therefore $3.75.

Table showing yields of different crops and value of water applied.

Crop.	Acreage.	Yield.	Value.	Approximate volume of water applied to each crop.	Value of water per acre-foot.	Depth to which land was covered for each crop.
		Bushels.		*Acre-feet.*		*Feet.*
Wheat	1,279	23,164	$13,898.40	6,052.57	$2.29	4.73
Oats	968	21,206	11,663.30	5,043.81	2.31	5.21
Corn	958	17,669	6,184.15	2,774.09	2.19	2.90
Potatoes	36	2,880	1,440.00	72	20.00	[1] 2
Alfalfa	1,863	[2] 9,700	43,650.00	11,144.41	3.92	5.98
Garden	18	....	[1] 500.00	36	13.90	[1] 2
Total	5,122	....	77,385.85	25,122.88	[3] 3.08	[3] 4.90

[1] Estimated. [2] Tons. [3] Mean.

DUTY OF WATER ON THE LARAMIE PLAINS FOR 1899.

By W. H. Fairfield.

The Laramie Plains are situated about 75 miles from the eastern and near the southern boundary of Wyoming. The altitude is 7,000 feet. The plains in the vicinity of Laramie are popularly known as the Laramie Plains, but in reality the Laramie Plains extend much farther north and west. They are bounded on the east and north by the Laramie Mountains, on the west by the North Platte River and the Medicine Bow Mountains, with the exception of the elevated portion extending east from the Platte lying just north of the Medicine Bow River, and on the south by the junction of the Medicine Bow and Laramie mountains. This includes an area of something over 4,000 square miles. The northern and northwestern portions of the plains are drained by the North Platte River, while the southern portion is drained by the Laramie River. Along these streams and their tributaries ranches are irrigated and native hay is grown. The practice in vogue is to take out the ditches and flood the prairie. The wild grasses are stimulated to greater growth, but on account of their being habituated to growing only in dry soils they are drowned out in from one to three years, and other species, which are better adapted to the changed conditions brought about by irrigation, gradually take their places. It is from these species that the greater part of the hay is obtained. Small quantities of potatoes, oats, barley, and wheat and a few vegetables are sometimes grown on these ranches. Owing to the altitude of the Laramie Plains the growing season is short and rather cool, especially at night. Under these conditions only the hardier farm and garden crops can be grown. The small grains do admirably, and each successive year sees more of them grown. The main crop grown as yet is native hay. This yields, depending on the care given in irrigation, from a small fraction of a ton to a ton, and in some especially favored locations over a ton, per acre. It would be

hard to estimate the average yield obtained; perhaps one-half ton per acre would not be far from the correct figure.

The Pioneer Canal diverts water from the Big Laramie River near where it leaves the mountains and irrigates a territory above the river bottoms. Its intake is about 25 miles above Laramie and it extends a mile or two below the city. Under this ditch some farming has been begun. The Wyoming Agricultural Experiment Station farm, which is located 2 miles west of Laramie, is watered by this canal.

In the spring of 1899 two ranches under this canal were selected on which to carry out some investigations relative to the duty of water on the plains. The farms are situated, one about 16 miles above Laramie and the other one-half mile west of the city. The soils are very different in composition. That on the upper one, Mr. John Sigman's ranch, is sandy and contains a great deal of gravel. The lower one, Mr. Cassius Webber's ranch, has a soil which, though it would be classified as a sandy loam, has the soil particles in such a fine state of division and is so thoroughly intermixed with stucco that it has the effect of a clay loam on percolation, which proceeds very slowly. The soil of each farm is representative of that in the vicinity, and the methods of irrigation and cultivation illustrate very well the general practice of farmers under the canal.

The Pioneer Canal Company makes contracts to furnish the consumer a continuous flow of water at the rate of 1 cubic foot per second for every 70 acres of land. Up to the season of 1900 but little effort was made to measure the water delivered to the various irrigators. As the supply was usually sufficient, each was allowed to take about what he thought he required, though this practice sometimes caused a scarcity of water at the lower end of the canal.

USE OF WATER ON MR. SIGMAN'S RANCH.

The water used on this ranch was measured in the lateral about 100 feet from the canal and something over one-eighth of a mile from the ranch. No estimate was made of the loss in the lateral, though the loss from seepage must have been considerable on account of the porous nature of the soil. The duty of water was determined, therefore, on the basis of the quantity delivered from the canal and not on that actually applied to the land.

Mr. Sigman first used water on May 26. It was impossible to supply him with a register before July 11, so between these dates the amount of water used is computed from the depth flowing over the weir as measured by Mr. Sigman. As these measurements were not taken often enough to record the usual variation in the flow, the volume of water reported as used during this period is only an estimate. On July 11 the register was started, and with the exception of about two weeks in August, when the clock was out of order, a fairly satisfactory record of the flow of water was obtained for the remainder of the

season. Mr. Sigman had the care of the instrument, changed the sheets, etc.

The soil on this ranch, as previously mentioned, contains a great deal of coarse sand and gravel, the formation extending to a depth of at least 10 feet, on account of which the land absorbs an unusual amount of water. Water was applied to 60.6 acres of prairie or native meadow, 4.3 acres of newly sown clover, and 0.17 acre of garden. There were also 6.4 acres of potatoes to which it was not necessary to apply water, since they were fully irrigated by seepage from the ditch leading to the clover field on the west, the flooded meadow on the south, and the garden in the northeast corner. This makes a total of about 71.5 acres served by the water passing the weir.

On July 22 the water was shut off entirely to allow the meadow to dry. It was turned on again August 13. More was used for the rest of the month than is customary where native hay alone is raised, but other crops gave use for the water during the latter portion of the season.

The following table gives the quantity of water used each month and the depth to which it covered the 71.5 acres watered, together with the depth of rainfall each month:

Water used on Sigman's ranch, season of 1899.

Date.	Water used.	Depth over land.	Rain-fall.	Total depth of water received by land.
	Acre-feet	*Feet.*	*Foot.*	*Feet.*
May 26 to 31	18 53	0.26	0.031	0.291
June	110.34	1.54	.092	1.632
July	29.93	.41	.167	.577
August	48.42	.68	.119	.799
September	15.31	.21	.014	.224
October 1 to 8	20.34	.28	.094	.374
Total	242.87	3.38	.517	3 897

The rainfall as given is only approximate, as it is the precipitation at Laramie, 16 miles distant, taken from the record kept by the meteorological department of the experiment station. The rainfall given for May and for October is for the entire month in each case.

The yield of hay from the meadow was practically nothing. Mr. Sigman states that he cut over, perhaps, 20 acres, from which he got four loads, and that the rest made good winter pasture. As stated, it takes from one to three years of irrigation to convert the prairie into productive hay meadow and the fact that this was only the second season of irrigation will explain why the yield was not greater.

The potatoes yielded about 7,000 pounds of marketable tubers per acre.

The clover being sown in the spring of the same season did not make sufficient growth to be cut.

Besides this land there were 9.3 acres in cultivation which were not irrigated. This land lay north of and on slightly higher ground than the clover and potato field. This included some wheat, oats, and a narrow strip of potatoes. Although there was no water applied to the surface of this land it received enough moisture by seepage from the canal to produce fair crops. For 8 miles or more along the canal in the neighborhood of Sigman's ranch an immense amount of seepage takes place. For 1 or 2 miles or more below the canal, or as far below irrigated land, moisture shows on the surface of the soil and produces a decided increase in the growth of grass. The loss from this portion of the canal by seepage is certainly excessive, but so far no effort has been made to determine the amount.

The duty of water, not only for the amount turned into the canal but also for the amount delivered to each consumer, is low along this portion of the canal on account of this loss.

USE OF WATER ON MR. WEBBER'S RANCH.

This ranch is near the lower end of the canal. The flow of water was measured in the lateral near the canal and a little less than one-half mile from the farm. Here, also, no measurements of the loss from the lateral by seepage were made, but owing to the rather impervious nature of the soil and the fall of the ditch it probably did not amount to much. Part of the land receives some seepage from the canal. There were 17.1 acres of land which had been sown with alfalfa in the spring, 2.7 acres of grain, and 1 acre of garden. The rest of the place was irrigated for native hay. The following table gives the quantity of water used each month:

Water used on Webber's ranch, season of 1899.

Date.	Water used.	Depth over land.	Rainfall.	Total depth of water received by land.
	Acre-feet.	*Feet.*	*Foot.*	*Feet.*
June 7 to 30	53.53	0.67	0.092	0.762
July	37.31	.47	.067	.537
August	27.59	.34	.119	.459
September	22.47	.28	.014	.294
October 1 to 8	12.89	.16	.094	.254
Total	153.79	1.92	.486	2.406

The rainfall is taken from the record kept by the meteorological department of the experiment station at Laramie. The total rainfall for June and October are given. The writer had the personal care of the register in this case.

On account of some repairs on the lateral, Mr. Webber did not begin to irrigate until June 7. This is much later than is customary, as

most ranchmen turn the water out on their meadows as soon as it comes down the ditch, which is from May 1 to 15. This will make the duty of water used on this place higher for the season than usual. The streams are high during May and June, and consequently the ditches have all the water they can carry, and it is during this season especially that large amounts of water are applied to the meadows. Ordinarily but little water is used during August, September, and October, but considerable was used this year on alfalfa on this farm.

It is impossible to get data from which to estimate the yield of hay, but the amount produced was an average crop for such meadows. The newly seeded alfalfa made a thrifty growth and yielded a light crop. The grain was cut for hay.

DUTY OF WATER FOR SPECIAL CROPS THE FIRST YEAR THE SOD IS PLOWED, 1899.

In the spring of 1899 the Wyoming Agricultural Experiment Station farm was enlarged by the addition of 80 acres of prairie adjoining it on the south. About half of this was broken and put into crops. A record was kept of the amount of water used on each crop. The loss of water from the lateral between the weir and the crop in question was not accounted for. The loss, however, was not great, for the laterals, without exception, had plenty of fall and the soil is close in texture and of such a consistency that water percolates very slowly through it. This is especially noticeable when the land is being flooded from the length of time it takes for it to become sufficiently soaked or wet. More water is required the first year land is cultivated than afterwards. There is reason to believe that there was not enough water applied, nor that often enough, on the two following crops to obtain the best results.

From May 5 to 9, 13.47 acres of Surprise oats were drilled in, which was immediately after the sod had been broken. The depth of breaking was between 3 and 4 inches. The first irrigation occurred between July 1 and 11 and enough water was applied to cover the land to a depth of 1.47 feet. From August 2 to 4 the second irrigation was begun, but only a small part of the field was gone over. Enough water was applied, however, to cover the field to a depth of 0.17 foot, making a total depth for the two irrigations of 1.64 feet. The rainfall for the growing season was 0.42 foot. The yield per acre of straw and grain was 1,317 pounds and of grain 558 pounds. This is a small yield, but perhaps not much under the average crop obtained from land the first year from the sod. The first irrigation was not given as early as it should have been, for the grain was suffering for ten days at least before the water was applied, and the second irrigation was too meager to do much good. These two factors made the crop lighter than it otherwise would have been.

A field of 10.83 acres of Highland Chief barley was drilled in May 12 to 14, just after the land was broken, the depth of plowing being the same as on the oat ground. The grain came up well and seemed thrifty until about August 7, when the first heads appeared. From this time on it developed very slowly. On part of the field the grain did not head till two or three weeks later and did not have time to ripen before frost. In fact, about one-fourth of the field was not even cut over, as the grain was so thin and short. No cause can be given for this failure other than that the season was unfavorable and that the land was in poor condition. The first irrigation extended from June 28 to July 6, and enough water was applied to cover the land to a depth of 1.32 feet. The second irrigation occurred between July 26 and August 1, the depth of water applied being 0.58 foot, making a total for the two irrigations of 1.9 feet. The total rainfall from May to October, inclusive, was 0.42 foot. The yield per acre was 837 pounds of straw and grain, or 240 pounds of grain alone.

IDAHO.

DUTY OF WATER IN IDAHO.

By D. W. Ross, *State Engineer.*

BOISE VALLEY.

During the early part of the irrigating season of 1899 several stations were established in Boise Valley for the study of the duty of water in irrigation. Measurements were made at the head of certain laterals of the quantity of water diverted for use by the irrigator, while the time and place of its use were also noted. From this data we were able to determine the quantity of water actually applied in irrigation to each tract of land. As there was no effort on the part of the irrigator to use less water than usual, the results obtained illustrated only the practices of the irrigator.

Observations were continued this season in Boise Valley at the station established in 1899 on the farm of Mr. A. F. Long, 5 miles northeast from Nampa. The tract irrigated during the season of 1900 embraced 132 acres, which included 105 acres irrigated in 1899, together with 22 acres of newly seeded alfalfa also sown to oats. The land slopes toward the southwest, has thorough drainage, and the surface of every field had been carefully leveled or smoothed previous to seeding. Of the area irrigated 40 acres was orchard; the remainder, 92 acres, while divided into several tracts and irrigated separately, was all seeded to alfalfa.

The orchard was irrigated from furrows made parallel to the tree rows while the other tracts were flooded.

The soil is a rich lava formation, with small lava bowlders on the ridges. It is about 18 inches to a subsoil, which consists of a porous hardpan through which water sinks very rapidly.

The accompanying diagram (fig. 23) shows the system of distrib uting laterals, also the subdivisions of the farm. The water was measured at the margin of the farm.

In irrigating the full head of water was applied to these subdivisions in turn or rotation, and in keeping the record of such irrigations the tracts or lots were designated by the numbers shown on the diagram.

It will be seen from the diagram that a head of water can be used with great economy in the irrigation of these tracts, the waste or run-off from the upper division being utilized on the lower sections. It is even possible to irrigate the orchard tract with waste water from the meadow land. This was not done, however.

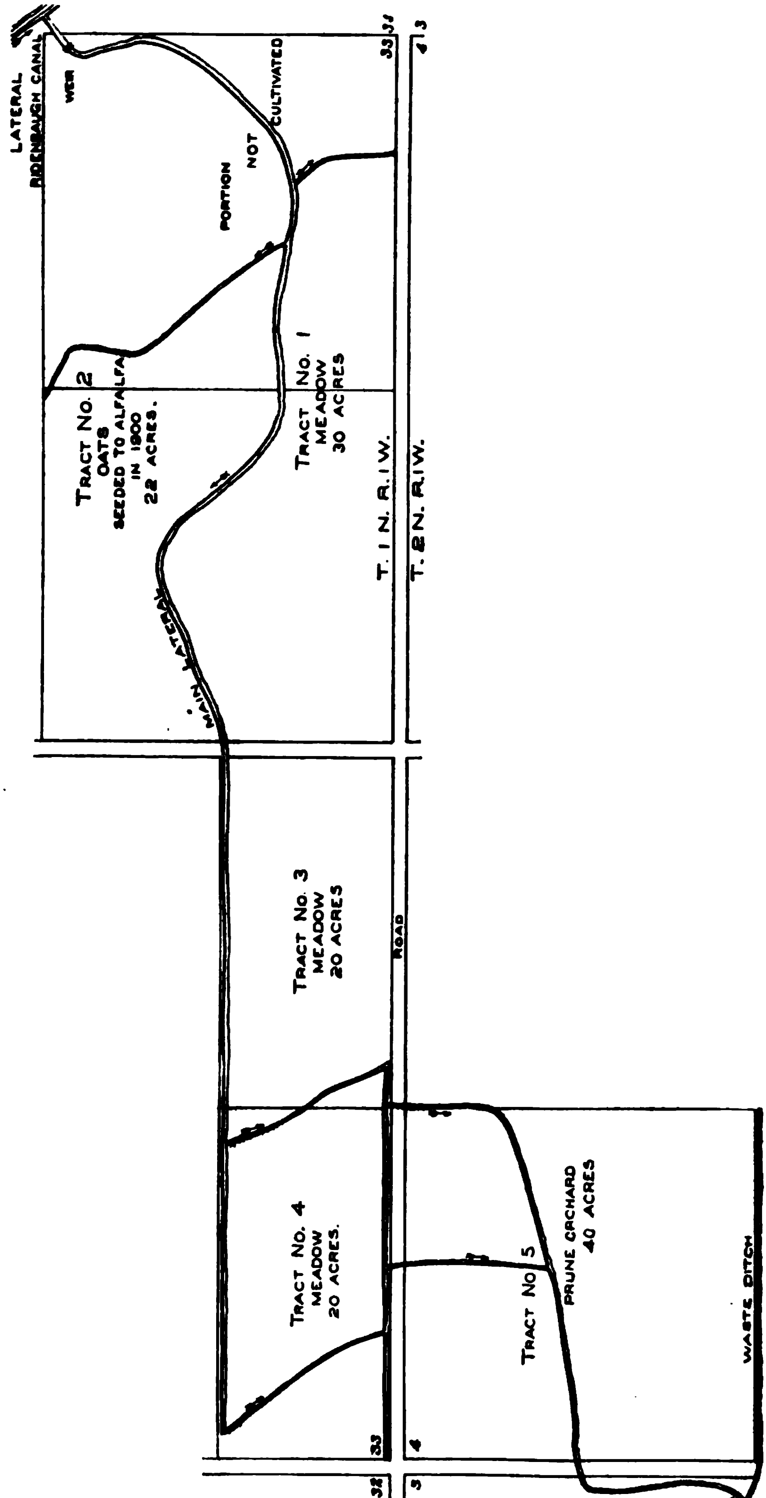


FIG. 23.—Plat showing system of distributing laterals on farm of A. F. Long, Boise Valley, Idaho.

While the conditions were very favorable for utilizing a flow or head that would reduce this run off to a minimum, no attempt was made toward economizing the water, but a head nearly uniform in volume flowed throughout the greater portion of the irrigating period. The water which as a result of this practice ran off the fields from time to time was not lost in this case, but was caught up in a "company lateral" a few rods below the orchard. The amount of this run off was not determined. Mr. Long obtains water for the irrigation of his land from the Boise and Nampa or "Ridenbaugh" Canal, a full description of which was given in my report on the duty of water for 1899.[1]

The price charged for the delivery of water is at the rate of $75 per cubic foot per second flowing continuously throughout the irrigating season. Until two years ago the charge for water from this canal was $1.50 per acre. The rules in force at that time allowed a maximum irrigating head of one-fiftieth of a cubic foot per second, or 1 inch to each acre irrigated. It was found that this system was leading to very wasteful habits among the irrigators, so the charge for service was established on the present basis. Farther on I have tried to show why this system fails to increase the duty of the water delivered by this canal.

The following table gives the quantity of water used each day during the irrigating season:

Quantity of water used each day by A. F. Long during the season of 1900.

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	0.84	3.80	3.80	4.25	3.16
2	....	1	3.80	3.80	4.25	2.80
3	....	1	3.75	3.80	4.20	2.80
4	....	.33	3.55	3.70	4.22	....
5	....	1.42	3.50	3.86	4.35	....
6	....	3	3.55	4	4.12	....
7	....	2.95	3.60	4	3.80	....
8	....	2.90	3.66	3.95	3.72	....
9	....	2.70	3.20	3.75	4.17	....
10	....	2.50	2.55	3.70	4.20	....
11	....	1.45	1.30	3.75	3.52	....
12	....	....	1.33	3.74	1.70	....
13	....	....	2.70	3.76	1.60	....
14	....	....	2.70	3.59	1.70	....
15	....	....	2.70	4.30	1.75	2
16	....	....	2.78	4.75	4.14	3.90
17	....	....	2.90	3.57	4.40	3.90
18	....	....	2.95	3.40	2.20	3.90
19	....	....	2.90	3.60	3.60	3.65
20	....	....	2.90	4.30	3.37	3.45
21	....	....	2.90	4.29	3.15	3.40
22	....	....	2.80	4.25	3	1.70
23	....	2.21	2.60	4.40	3.10	....
24	....	3.14	2.80	4.50	3.75	....
25	....	3.05	2.80	4.10	4.02	....
26	1.10	.43	2.80	4.30	3.60	....
27	2.75	2.60	1.97	4.55	3.17	....
28	2.60	2.60	....	3.90	2.75	....
29	2.36	3.58	....	4.40	2.47	....
30	2.25	3.75	1.90	4.20	2.15	....
31	1.71	3.80	....	4.30	2.82	....
Total	12.77	45.25	80.69	124.31	103.24	34.66

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

The record was begun April 25 and continued until September 22. During this period water was used one hundred and twenty-seven days. The quantity used amounted to 400.9 acre-feet, or an average of 3.16 acre-feet per day. This would require a flow of 1.59 cubic feet per second; and the amount was used on 132 acres, or 1 cubic foot per second for 83 acres.

The diagram (fig. 24) shows graphically the acre-feet used each day and the system of rotation followed in applying the irrigating head to the land. Thus, water was turned onto tract No. 1 on April 25; it was used on this tract until April 28, when it was turned onto tract No. 3; here it was allowed to run until April 30, when it was changed to tract No. 4. It was used on tract No. 4 until May 4, when it was changed to tract No. 2, upon which it was left flowing until May 11. From May 11 until May 23 the water was turned off entirely. On May 23 the irrigating head was again turned onto tract No. 2, when it flowed for three days, then changed to tract No. 3. In this manner the irrigating head was rotated from tract to tract throughout the entire season. The diagram referred to illustrates the system followed, and also shows the quantity of water used on each tract at each irrigation.

The following table shows the area of each tract, the kind of crop, the dates of irrigation received during the season, the water used on each tract in each irrigation and for the season:

Water used on farm of A. F. Long.

No. of tract.	Crop.	Area.	Date of irrigation.	Water applied each irrigation.		Total water applied.	
				Quantity.	Depth.	Quantity.	Depth.
		Acres.		*Acre-feet.*	*Foot.*	*Acre-feet.*	*Feet.*
1	Alfalfa	30	Apr. 25-28	7.75	0.26	86.02	2.87
			June 3-5	14.45	.48		
			June 24-27	11.58	.39		
			July 8-12	19.02	.63		
			July 30-31	12.40	.41		
			Aug. 17-18	6.60	.22		
			Aug. 25-26	7.22	.24		
			Sept. 1-3	7	.23		
2	Oats seeded to alfalfa	22	May 5-11	16.92	.77	40.39	1.84
			May 23-25	8.40	.38		
			June 12-14	8.07	.37		
			July 13-14	7	.32		
3	Alfalfa	20	Apr. 29-30	4.46	.22	72.98	3.65
			May 26-28	7.34	.37		
			July 5-7	11.71	.59		
			July 25-29	13.10	.66		
			Aug. 7-9	11.57	.58		
			Aug. 21-23	9.23	.46		
			Sept. 15-18	15.57	.78		
4	Do	20	May 1-4	3.73	.19	78.65	3.93
			May 29-June 2	15.11	.76		
			June 30-July 4	15.15	.76		
			July 21-24	17.37	.87		
			Aug 10-11	8.42	.42		
			Aug. 19-20	8.54	.43		
			Sept. 19-22	10.33	.52		
5	Prune orchard	40	June 6-11	16.11	.40	122.	3.06
			June 15-23	22.86	.57		
			July 15-20	27.71	.69		
			Aug. 1-6	25.54	.64		
			Aug. 12-16	12.31	.31		
			Aug 24-	4.40	.11		
			Aug. 27-Sept. 1	13.32	.44		

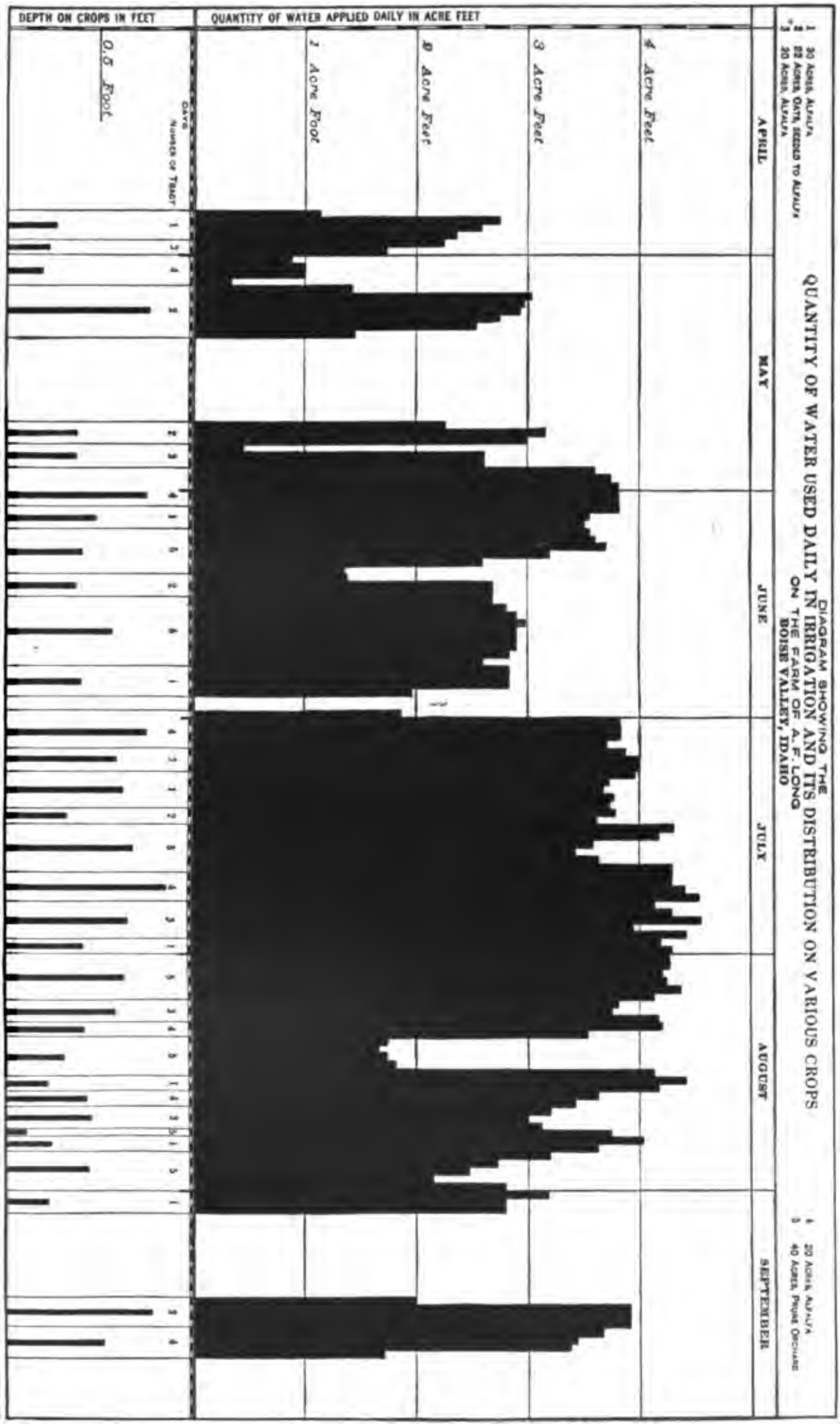


FIG. 24.—Diagram showing quantity of water used daily on farm of A. F. Long.

Inasmuch as tracts 1, 3, and 4 are meadows of about the same age, they might be considered together. Taken together, then, we find that 237.65 acre-feet was used on them during the season, or enough to have covered them to an average depth of 3.39 feet, or the equivalent in rainfall of 40.7 inches.

The orchard was given seven irrigations, occupying 38 days out of the 127 during which water was applied on this farm. While the irrigating head was generally reduced during the irrigation of the orchard, the quantity used per acre was nearly equal to that used on the alfalfa, and more than twice as much water was applied to the orchard this season as in 1899.

It has been the theory in this valley that orchards required less water than anything else grown by irrigation. It has been demonstrated, however, during the past two years that many orchards were actually suffering from lack of water. This season water was more generously applied to orchard ground, and a greater tree growth, increased size, and a better quality of fruit than was obtained in former years was the result.

It will be observed from these tables that the period of greatest use this season was from the beginning of July to the 18th of August, when the average daily use was 3.8 acre-feet, or an amount equal to nearly 1 per cent of the quantity used during the entire season. This proportion between the quantity used each day of the period of greatest use and the quantity used during the entire irrigating season appears to be about the same in this State under ordinary conditions, and might with safety be taken as a basis for fixing the maximum capacity of irrigation works.

During 1899 water was applied to meadow land to an average depth of 3.09 feet; during 1900 to a depth of 3.39 feet; and while in 1899 water to a depth of 1.27 feet was used on the orchard, in 1900, as before stated, more than twice that depth, or 3.06 feet, was applied. The average depth used on all the land in 1899 was 2.40 feet; in 1900 it was 3.03 feet. The total rainfall at this station during the irrigating period was 3.25 inches or 0.27 foot.

The following table will show the duty of water on this farm, taken as a whole:

Duty of water on the farm of A. F. Long, 1900.

Area irrigated .... acres..	132
Quantity applied .... acre-feet..	400.90
Depth of water used in irrigation .... feet..	3.03
Depth of rainfall .... foot..	.27
Total depth of water received by land .... feet..	3.30
Average quantity used during each day's irrigation..acre-feet..	3.16
Average volume used during each day's irrigation, cubic feet per second	1.59
Area irrigated per cubic foot per second .... acres..	83

The last statement in the above table means that the average daily duty of 1 cubic foot per second was 83 acres. As a basis for estimating the volume of water required for the irrigation of a large area this might be of value. As a basis for an estimate of the volume required for the irrigation of a small tract of land, however, it is very misleading.

The average quantity used each day was 3.16 acre-feet. This is equal to the flow of 1.59 cubic feet per second for a period of twenty-four hours. While this was the average volume used each day, it was not distributed over the entire farm, but over tracts, the largest of which was 40 acres.

Examining the table of amount used daily, we find that during the month of July a head of more than 2 cubic feet per second was used in the irrigation of tracts of only 20 acres each, or at the rate of 1 cubic foot per second for 10 acres, or 5 inches to the acre, while the average volume used per acre on the whole tract was at the rate of only 0.6 inch per acre.

Every practical irrigator appreciates the advantages of a serviceable head in the irrigation of crops during the hot periods, the saving in both time and water being great when one is able to pour a large stream over the hot earth. This was an advantage turned to account by Mr. Long in moving a good working head of water from field to field, but one which would be denied an owner of any one of the subdivisions of this farm were he restricted to a use of but "an inch to the acre," which allowance is popularly supposed to be generous.

This will explain why the water contracts which have been entered into from time to time between ditch companies and users of water, and by-laws, rules and regulations of many farmers' irrigation companies have failed in their attempt to establish standards which the irrigator does not, and can not, follow in practice. All such contracts and by-laws should make such provisions as will entitle the smallest user or stockholder to a serviceable head of water whenever it comes his turn to irrigate. The right to a continuous flow should be ignored entirely, for water is not supplied continuously to every acre of ground, but is only applied at intervals. The right to a certain maximum depth during each season should be provided for, but this quantity should be applied at such times and in such amounts as will reduce both the time required and amount used for irrigating to a minimum. Rotation in the use of heads is the basis of this system, and should be carried on among the small farmers as it is practiced on the large farm of several subdivisions.

The average daily flow of the "Ridenbaugh" Canal this year was nearly 400 cubic feet per second. This water was applied to 19,000 acres of land, or at the rate of 1 cubic foot per second for each 47.5 acres irrigated. This duty is very low. It is true there is a great loss of water from seepage and evaporation in the long laterals, but

a large volume of waste water was gathered in the drainage ditches this season and used a second time in irrigation. This amount is estimated by the manager, Mr. Green, at 30 cubic feet per second, and would make up for a large percentage of loss from seepage.

Mr. Long was entitled, according to the rules of the company, to a flow of nearly 5 acre-feet daily for a period of one hundred and eighty-three days, or 915 acre-feet, for which he paid $187.50. He drew water from the canal but one hundred and twenty-seven days, during which time he used 400.9 acre-feet, or only 43 per cent of the quantity for which he paid, and a large portion of this amount ran off his fields and was caught up in the company's lateral. The maximum allowance which he paid for would have covered his land to an average depth of nearly 83 inches. This would have cost him at the rate of 20.5 cents per acre-foot. Since he used considerably less than one-half his allowance, he paid more than twice this rate, or 46.9 cents per acre-foot.

The study of Mr. Long's methods is not of great value in determining with accuracy the quantity of water required to grow certain crops; indeed, it fails to indicate how much was actually absorbed by the soil and how much ran off the surface; but it does show clearly why water is used wastefully in the Boise Valley.

It will not be possible to induce farmers to use water with economy until they are charged for what they use only. Mr. Long does not represent the wasteful irrigator; on the contrary, he represents the careful user, as these records show. He used plenty of water, yet note the wide margin between the quantity actually diverted from the canal and the quantity paid for and to which he was entitled. When irrigators draw on this margin they take water that they do not actually need. The result is, first, a loss of revenue to the company, for its canal has been running bank full for the past two seasons, and, second, a loss to the public, for the water that is thus wasted should be supplied to other lands.

The low average duty of water under this system proves that the majority of farmers are using more water than they need, and unless water is used with greater economy than it is to-day, the development of the Boise Valley will remain at the point where it has been for nearly three years past.

It should be self-evident to anyone that the only way the cultivated area in this valley can be increased is either by enlarging the present canals or increasing the duty of the water already being diverted from the river. Another thing should be self-evident: Since the irrigator is wasting the water, he alone can save it, but he will not practice economy unless he is benefited in some manner thereby. It is true that in many cases he could effect a great saving of water by leveling up the surface of his fields, but this is not the point with the average

irrigator under a rental system; he pays for the delivery of his water and he usually demands all that he pays for whether he needs it all or not, and he will not become a willing party to any scheme for increasing the duty of water unless he is allowed the benefits to be derived from his own thrift. He should be charged only for the water actually used on his land. This is the principle followed by the farmer when he sells the product of his farm; he is paid for only what he delivers. In order to carry out this principle in connection with the delivery of water in a manner easily understood by the farmer, the rate should be based upon a unit in general use among irrigators, as 1 inch flowing for 24 hours. Then when the farmer orders a head of water turned onto his land he will know just how much it will cost for each day's run. He must pay for it while it runs and no longer, and will therefore not allow it to run to waste.

The company should take charge of the entire lateral system, relieving the farmer of "ditch tending," and see that each irrigator gets the head ordered. The management will then be in a position to establish a system of rotation in the distribution of irrigating heads to the users.

When the individual irrigator has reduced his water bill to a minimum, which he will be sure to do in a short time under this system, he will have raised the duty of water to the maximum, and in doing this he is a public benefactor to the extent of the water he has saved, for all that he saves in the irrigation of his own land will be used in reclaiming other lands from the desert.

THE PAYETTE VALLEY.

C. G. GOODWIN'S FARM.

A station was established on the farm of Mr. C. G. Goodwin, in the Payette Valley, and a record of the flow of water used begun on May 3, 1900.

The cultivated portion of this farm contains 54.5 acres, divided as follows: Alfalfa meadow, 31.5 acres; orchard, 3 years old, 5 acres; oats, seeded to alfalfa in 1900, 10 acres, and 8 acres of cantaloupes. The tract of 31.5 acres, classed as alfalfa, contains 15 acres of old meadow, 8½ acres seeded in 1899, and 8 acres of oats seeded to alfalfa in the spring of 1900.

Water is obtained from the Payette Valley Irrigation and Water Power Company's canal, the headgate of Mr. Goodwin's supply lateral being but a few rods from his land. The flow through this headgate was recorded automatically by a register, from May 3 to the close of the irrigating season, which, on this farm, was August 29. Water was used for a few days (from April 17 to 24) before this

register was established, and the quantity noted for that period is from a record kept by Mr. Goodwin.

The subdivision of this farm into irrigation tracts and the system of distributing laterals are shown on the diagram (fig. 25). The main lateral runs north along the west side of this farm for a distance of 1,320 feet, then parallels the main canal around the north end of the tract.

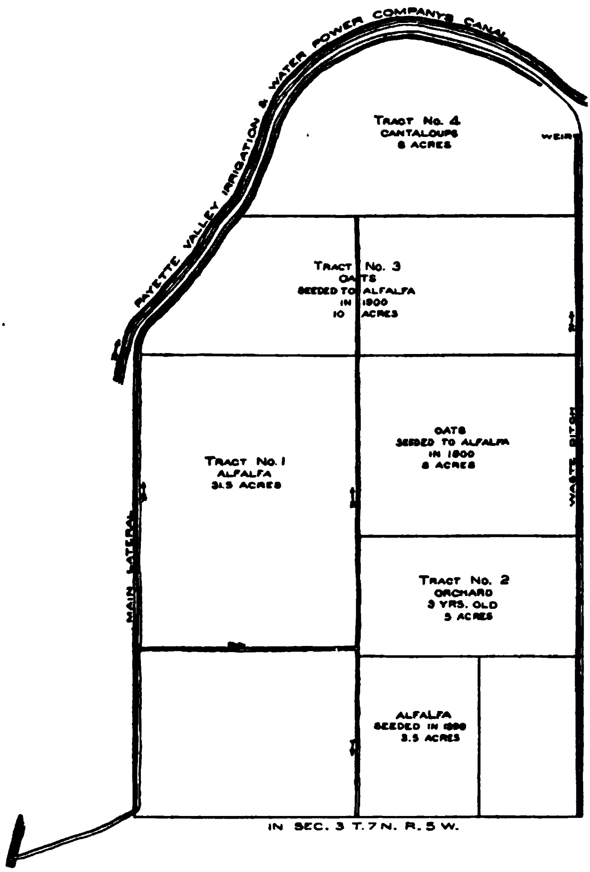


FIG. 25.—Plat showing system of distributing laterals on farm of C. G. Goodwin, Payette Valley, Idaho.

Distributing laterals carry the water to the several subdivisions as shown on diagram, and a waste ditch constructed along the east line of the farm collects the run off which occurs at each irrigation. At the lower end of this waste ditch a 12-inch trapezoidal weir was placed, and observations made several times each day of the volume flowing over the same. The water flowing over this weir was not used again on this land and therefore represented the run off, in this case waste.

No account was kept of the surplus water which ran off a high tract onto one of lower elevation until it reached the waste ditch, for in flowing over the lower tract a portion of it, and sometimes all of it, was absorbed.

The soil is a deep sandy loam, sloping gently toward the east and north, and absorbs water very readily.

The following table shows the quantity of water turned on each day; also the quantity which ran off the land and collected in the waste ditch, and the net amount used:

Water used on the farm of Mr. C. G. Goodwin during the season of 1900.

Day.	April.			May.			June.			July.			August.		
	Applied.	Run off.	Used.	Applied.	Run off.	Used.	Applied.	Run off.	Used.	Applied.	Run off.	Used.	Applied.	Run off.	Used.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	......	......	......	......	......	......	3.40	0.77	2.63	2.33	0.17	2.16	1.80	0.14	1.66
2	......	......	......	......	......	......	3.03	.90	2.13	2.84	.50	2.34	1.65	.52	1.13
3	......	......	......	0.68	......	0.68	2.07	.38	1.69	2.70	.40	2.30	1.82	.23	1.59
4	......	......	......	1.70	......	1.70	2.88	1	1.88	2.65	.20	2.45	1.87	.50	1.37
5	......	......	......	1.30	......	1.30	1.70	.86	.84	2.47	.71	1.76	1.60	.10	1.50
6	......	......	......	1.20	......	1.20	1.20	.17	1.03	2.30	.90	1.40	1.76	.78	.98
7	......	......	......	.96	......	.96	.28	......	.28	2.34	.46	1.88	2.02	.42	1.60
8	......	......	......	.62	......	.62	......	......	......	2.24	.77	1.57	2	.79	1.21
9	......	......	......	.20	......	.20	......	......	......	2.28	.47	1.81	2	.83	1.17
10	......	......	......	......	......	......	......	......	......	1.83	.47	1.36	1.97	.35	1.62
11	......	......	......	......	......	......	......	......	......	.13	......	.13	1.81	.31	1.50
12	......	......	......	......	......	......	......	......	......	......	......	......	2.15	.22	1.93
13	......	......	......	......	......	......	......	......	......	......	......	......	2.35	.17	2.18
14	......	......	......	......	......	......	......	......	......	......	......	......	2.18	1	1.18
15	......	......	......	......	......	......	......	......	......	......	......	......	2.24	.28	1.96
16	......	......	......	......	......	......	......	......	......	......	......	......	2.16	1.03	1.13
17	......	......	......	......	......	......	1.41	.05	1.36	......	......	......	2.60	.65	1.95
18	2.40	0.60	1.80	......	......	......	2.60	.30	2.30	......	......	......	2.39	.08	2.31
19	2.40	.60	1.80	......	......	......	2.32	.35	1.97	......	......	......	2.55	.16	2.39
20	2.40	.60	1.80	......	......	......	2.65	.80	1.85	2.06	.28	1.78	2.55	.46	2.09
21	2.40	.60	1.80	......	......	......	2.58	.41	2.17	1.16	.19	.97	2.29	.45	1.84
22	2.40	.60	1.80	......	......	......	2.44	.02	2.42	......	......	......	2.35	.53	1.82
23	2.40	.60	1.80	......	......	......	2.23	.57	1.66	......	......	......	2.45	.42	2.03
24	2.40	.60	1.80	1	......	1	2.41	.41	2	......	......	......	2.45	.51	1.94
25	......	......	......	2.30	......	2.30	2.40	.95	1.45	......	......	......	1.10	.41	.69
26	......	......	......	.70	......	.70	2.35	.48	1.87	......	......	......	......	......	......
27	......	......	......	2.45	0.07	2.38	2.35	.73	1.62	......	......	......	.95	......	.95
28	......	......	......	2.45	.45	2	2.30	.55	1.75	.54	......	.54	2.59	.87	1.72
29	......	......	......	2.37	1.11	1.26	2.39	.88	1.51	2.31	.26	2.05	1.05	.25	.80
30	......	......	......	2.22	.65	1.57	1.45	.40	1.05	2.07	.32	1.75	......	......	......
31	......	......	......	2.52	.30	2.22	......	......	......	2.17	......	2.17	......	......	......
Total	16.80	4.20	12.60	22.67	2.58	20.09	46.44	10.98	35.46	34.52	6.10	28.42	56.70	12.46	44.24

The regulations of the company, hereinafter referred to, would under ordinary circumstances have enabled the irrigator to plan the delivery and distribution of his water to suit the exact needs of the several tracts under cultivation; but all such plans were upset through several serious breaks which occurred on the main canal during the time when water was most needed. One of these breaks occurred in the early part of June, while two occurred during the hottest part of July. After the first break water was applied very generously as the best and cheapest insurance against damage in the event of a recurrence

of this trouble. The effect of the second break is noted on this diagram. Water reached the ranch again on July 20, but flowed for only two days when it ceased owing to the third serious break in the canal.

One effect of these breaks was to oblige Mr. Goodwin to devote nearly all his attention to the irrigation of the field of cantaloupes, his most valuable crop.

Water was turned onto the alfalfa first on April 18, where it flowed for seven days. It was not used again until May 3, when the cantaloupe field was irrigated; the head was turned off May 9. It rained on May 3, 11, 12, and 16, a total of 1.67 inches or 7.58 acre-feet over the tract of 54.5 acres. The irrigating head was used again on May 24 on the field of alfalfa, or tract No. 1. After running on this tract for one day, a portion of it was turned onto tract No. 3. On May 27 it was all used on this tract, where it ran until May 30, when a portion was turned onto tract No. 1, and the remainder onto tract No. 4. On June 3 the part used on the cantaloupes was added to the portion then running on the meadow, or tract No. 1, where it ran until June 5, when the head was reduced and turned onto the orchard, tract No. 2, where it ran until June 7, when, owing to a serious break in the main canal, the head gradually ran down and irrigation ceased. Water was available again on June 17, and flowed without interruption until July 11; then ceased on account of the second break. During most of this time the irrigating head was divided, a part being used on the oats or alfalfa, and a part on the cantaloupes or orchard. During this period the alfalfa received 2 irrigations, the orchard 2, the oats 2, and the cantaloupes 4 irrigations. Water was received again July 20, but owing to another serious break ceased flowing July 21. This short flow was all applied to the cantaloupes, and when the water was again delivered on July 28 they were the first to be irrigated. From this time on, owing to the condition of the main canal, the irrigating head was slightly reduced.

During the irrigating season, 177.13 acre-feet of water was applied in eighty-eight days, or an average of 2 acre-feet each day, which is equal to a rainfall of 0.44 inch. Of this amount 36.32 acre-feet, or about 20 per cent, ran off the land and was wasted, leaving 140.81 acre-feet absorbed by the soil.

Of the water applied to the alfalfa, 25 per cent ran off and was wasted, 28 per cent ran off the orchard, and 17 per cent ran off the oats, while only 9 per cent of the quantity applied to the cantaloupes was wasted. In the irrigation of the orchard it might be well to add that heads much larger than usual were used, and these for only a short time. This is not the usual method of irrigating an orchard, but was rendered necessary on account of the breaks which were occurring in the main canal.

The following table shows the quantity of water used each month and during the season in the irrigation of the different crops:

Water used on farm of C. G. Goodwin.

No. of tract.	Crop.	Area.	Date of irrigation.	Water applied each month.		Total water applied.	
				Quantity.	Depth.	Quantity.	Depth.
		Acres.		*Acre-feet.*	*Feet.*	*Acre-feet.*	*Feet.*
1	Alfalfa meadow of different ages.	31.5	Apr. 18-24; May 24-26	12.60	0.40	64.40	2.04
			May 31-June 5; June 21-30	22.60	.84		
			July 6-11; Aug. 13-17	6.69	.21		
			Aug. 21-25; Aug. 27-29	18.51	.59		
2	Orchard	5	June 6-7; July 2	1.10	.22	8.88	1.78
			July 4-5	.80	.16		
			Aug. 5-10	6.98	1.40		
3	Oats seeded to alfalfa	10	May 25-30	7.53	.75	40.14	4.01
			June 17-20	7.09	.71		
			July 2-5; July 31	11.22	1.12		
			Aug. 1-4; Aug. 18-20	14.30	1.43		
4	Cantaloupes	8	May 3-9; May 31	7.46	.93	27.39	3.42
			June 1-2; June 19; June 21; June 29-30	5.77	.72		
			July 1; July 10; July 20-21	9.71	1.21		
			July 28-30; Aug. 11-12	4.45	.56		
	Total	54.5				140.81	2.58

In the above table the quantity that ran off during each irrigation has been deducted, leaving the quantity actually absorbed by the soil. The table giving the quantity applied daily shows the amount of this run off.

The duty of water in this case is shown by the following table:

Duty of water on farm of C. G. Goodwin, 1900.

Area irrigated	acres	54.5
Water used	acre-feet	177.13
Depth of water used in irrigation	feet	3.25
Water wasted per acre	foot	.67
Average depth used	feet	2.58
Depth of rainfall	foot	.26
Total depth received	feet	2.84

The average quantity applied each day on this farm of 54.5 acres was 2 acre-feet. This would be a volume flowing at the rate of 1.01 cubic feet per second.

Mr. Goodwin makes the following report on the date of harvest and the yield of the various crops:

Lot No. 1, 31.5 acres, which consisted of 15 acres of old meadow, 8.5 acres of meadow seeded in 1899, and 8 acres of oats, seeded to alfalfa in 1900, yielded 90 tons of hay, harvested at three cuttings, viz: June 20, July 25, and September 20. No. 2, 5 acres was orchard, and nothing was raised save a small patch of potatoes which produced about 1 ton. No. 3, 10 acres, was oats with alfalfa sown at the same time, which yielded 15,000 pounds (oats), cut July 10; 15 tons of hay was cut off the same ground on September 20. No. 4, 8 acres of cantaloupes, from which 600 crates were gathered, which sold at an average price of 60 cents per crate.

The scarcity of water will be shown, also its irregularity, by the reports sent to you each week during the irrigating season. It will be shown that I have used more water on my cantaloupes than on anything else, which was not because they required more, but because I desired to insure the success of the crop that had cost me the most labor, also the one that would bring the most money. Through the breaks in the canal the hay was cut short at least one-fifth, the oats one-third (a break occurred just as they were heading), and the melons probably one-third.

It will be instructive to examine the water contract which covers this land and compare one of its provisions with the practice which is followed by Mr. Goodwin and other water users under this canal. The water right which is dedicated to this land provides that water shall be delivered during each irrigating season at the rate of 1 cubic foot per second to each 150 acres of land. It has been found that on small subdivisions of land this does not allow an irrigating head that can be used with economy; therefore this provision of the contract has been ignored, and the canal company for the past four seasons has been delivering water to its users at the rate of about 1 cubic foot per second for every 50 acres of land irrigated.

A notice was sent to the water users under this canal last April which stated that during the season of 1900 a charge would be made for the delivery of water at the rate of 75 cents per 150,000 cubic feet to all consumers having a water deed or contract and at the rate of $1.50 per 150,000 cubic feet to those not having such contract. The notice stated further that "the water is to be delivered only at such times and in such quantities as the consumer may desire," and that, "should the supply become exhausted before the close of the season and more water be desired, the same can be purchased. If, however, at the end of the season the consumer has not used the entire quantity to which he is entitled a rebate will be given." This rebate and the price charged for an extra supply were to be at the rate charged for the quantity originally contracted for.

The annual charge fixed by the contracts referred to in this notice is 75 cents per acre. The charge for this quantity (150,000 cubic feet) was based upon the continuous flow of one-half inch or the one-hundredth part of a cubic foot per second on 1 acre of land for 183 days, which is the full extent of the irrigating season as fixed by law. This would be equal to the flow of 91.5 inches or 1.83 cubic feet per second for one day and would cover 1 acre of land to a depth of 3.66 feet.

Although the rate of 75 cents per acre is not excessive, the irrigator was afforded an opportunity of reducing his water bill through this arrangement.

As before stated, the average quantity used each day was 2 acre-feet, or almost exactly 1 cubic foot per second. This is two and eight-tenths times the head provided for in the water right or contract covering this land—71 acre-feet. This would allow a maximum irrigating head of 18 inches, which, flowing for 183 days, would cover this tract to a depth of 2.4 feet. In irrigating the meadow under this arrangement a head of but 0.57 inch per acre would be allowed. More than three times that head was available under the system adopted this season.

The original contract provided for an annual charge of $1.50 per acre, which was afterwards reduced to 75 cents per acre; the price fixed this season is at the rate of 20.5 cents per acre-foot. This would be the cost of almost exactly one-half cubic foot per second, or 25 inches flowing for twenty-four hours, or a rate of 0.82 cent per 24-hour inch; or a head of 50 inches flowing for twenty-four hours will cost 41 cents. As the farmer orders a head of water of a stated number of inches turned on for a certain specified time, the basis of the charge for its delivery should have reference to the unit which he employs in his estimates in relation to the most essential features of irrigation, viz, the size of the irrigating head required and the time during which it must be used on various crops. He is always familiar with these two elements, and if he knows how much an inch flowing for one day will cost he can readily determine the cost of each irrigation without being first obliged to compute the cubic or acre-feet of water or reduce to other equivalents the number of inches which he had ordered.

The objectionable feature of the original contract or "perpetual water right" is not the rate, but the arbitrary duty of water fixed therein, without providing for the delivery of the allowance according to the custom which the very nature of the operation obliges the irrigators to follow. It was a wise provision made in this contract for the dedication of a right to the land; it was also well to provide a specific allowance of water to be delivered during each season; but the provision should have been made for the delivery of this allowance as it was needed by the farmer. This could be done only by providing for a system of rotation or use in turn by the irrigators of serviceable irrigating heads.

It is but fair to state that the company has virtually ignored this provision of its contract; still its existence in this instance shows the importance of carefully considering these very practical features of an irrigation project.

FARM OF N. C. PERCELL.

For the purpose of observing the practice followed in the irrigation of hay in the Payette Valley the farm or Mr. N. C. Percell was

selected and the water measured as it was used in the irrigation of 48 acres of alfalfa and timothy.

The land is situated about 3 miles below the town of Payette and receives its water from the Payette River via the Lower Payette Ditch. This ditch is owned by a company composed of those owning the land which it irrigates. After this ditch has been given its full capacity one share of the stock will entitle the holder to 20 miner's inches of water. At present it is the practice to divide the water pro rata among the stockholders. They are entitled to a continuous flow of their share, although many of the smaller users combine their shares and use this volume in turn or rotation.

The supply in the river is abundant, the flow at the intake of the canal is regulated by means of a diverting dam, the discipline of the

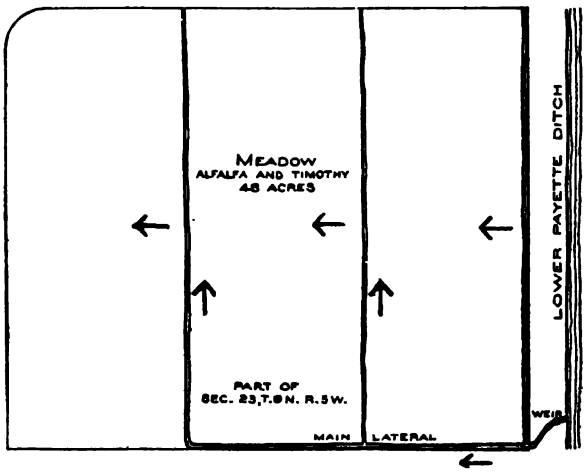


FIG. 26.—Plat showing system of distributing laterals on meadow of N. C. Percell, Payette Valley, Idaho.

users is excellent, and the service is good; hence the flow in the canal is very uniform.

Mr. Percell's land lies close to the canal, and water is measured to him over a trapezoidal weir and reaches his distributing laterals with practically no waste from seepage.

The soil is a sandy loam, 3 to 4 feet deep, with a subsoil of clean, almost white sand. The land has been in cultivation about seven years, and has always produced splendid crops. It slopes slightly toward the west, and is divided into three equal sections by the distributing laterals, which run north and south and parallel to each other. The diagram (fig. 26) shows the arrangement of these laterals and the subdivision of the tract.

In irrigating this tract water is turned into the upper lateral and flooded over the first subdivision of land, the run off being caught in the second head ditch, whence it floods over the second subdivision. After the first subdivision has been thoroughly soaked the water is

turned into the second head ditch and the second subdivision flooded, and so on until the entire tract has been irrigated. By this system of parallel head ditches the irrigating head is always under control and the waste is reduced to a minimum; in fact, Mr. Percell states there is no waste at all. The seepage and run off having been entirely eliminated, we have, then, in this case, the quantity of water actually used on the crop.

The following table shows the volume measured over the weir each day:

Water used each day on N. C. Percell's farm.

Day.	May.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	2.10	3.20	0.80	0.80
2	2.80	3.20	2.80	1.60
3	2.80	3.20	2.80	1.60
4	2.80	3.20	2.80	1.60
5	2.80	2.66	2.80	2.40
6	2.80		2.80	2.40
7	2.80		2.80	2.40
8	2.80		2.80	2.40
9	2.10		2.80	2.40
10			2.80	2.40
11			2.80	1.90
12			2.80	
13			2	
14			2	
15			2.40	
16			2.40	
17			2.40	
18			1.20	
28	2			
29	3.20			
30	3.20			
31	3.20			
Total	35.40	15.46	44	21.90

It will be seen from the above table that the period of greatest use occurred in July, when 44 acre-feet was supplied during a period of eighteen days, or at the rate of 2.4 acre-feet per day. This quantity of water, spread out over the entire tract, is equal to a rainfall of more than one-half inch.

Owing to the fact that the water was not applied continuously, a comparison of the quantity used each month will not be of any value.

The following table has been arranged to show the time of use, the quantity used and the depth of each irrigation, and the date of harvest and yield at each cutting:

Time of irrigating, quantity and depth of water used at each irrigation, and yield.

Date of irrigation.	Days.	Quantity.	Depth.	Date harvested.	Yield.	
					Total.	Per acre.
		Acre-feet.	*Feet.*		*Tons.*	*Tons.*
May 1 to May 9	9	23.80	0.50			
May 28 to June 5	9	27.06	.56	June 20	140	2.9
July 1 to July 18	18	44	.92			
August 1 to August 11	11	21.90	.45	Sept. 1	100	2.1
Total	47	116.76	2.43		240	5

The above table shows that forty-seven days were spent in giving the tract four irrigations. During this time 116.76 acre-feet of water was applied, 37 per cent of which was during the July irrigation. During that month the water was applied to a depth of 0.92 foot, while on the Long farm in the Boise Valley a depth of 1.24 feet was applied, a difference of 0.32 foot, or 25 per cent of the amount applied by Mr. Long. This is the percentage of run off on Mr. Goodwin's ranch in the irrigation of his alfalfa. Therefore we are very safe in assuming that not more than 75 per cent of the water applied by Mr. Long in the irrigation of his alfalfa soaked into the ground. This would make a depth of 2.54 feet during the season, or only 0.11 foot more than was applied by Mr. Percell. From this we feel safe in asserting that a depth of 2.5 feet, if properly applied, is sufficient water for the irrigation of meadow.

It will be observed that water was used but forty-seven days on this farm, although the canal delivered water for at least one hundred and fifty days during the irrigating season. The average head of water delivered during each day of its use in this case was 1.29 cubic feet per second, or at the rate of 1 cubic foot per second for 39.5 acres.

It will also be observed from the date of the several irrigations made by Mr. Percell that this head of water might have been applied to the irrigation of other tracts besides his own. The rules of the company, however, do not provide for a rotation of irrigating heads; but since Mr. Percell turned his irrigating head back into the main canal after each irrigation, it was probably used on other land, as the average duty of the flow of this canal was about 1 cubic foot per second to every 60 acres of land irrigated.

CONCLUSION.

I desire to urge in conclusion that the most significant feature disclosed in this investigation is not that water was applied to a certain depth during the season in the irrigation of various crops, but the incongruities found in the relation existing between the contracts and rules of companies delivering water to the users and the practice of these users.

In the case of Mr. Long, only 43 per cent of the quantity to which he was entitled was used by him. While there was a margin of 57 per cent of his season's allowance to his credit flowing in the canal, to have drawn on that margin would, in his case, have been deliberate waste. While 1 cubic foot per second had a duty on his land of 83 acres, had he used the volume paid for, 2.5 cubic feet per second, the duty would have been only 52.8 acres. The average duty under this canal system, irrigating 19,000 acres, was but 47.5 acres, or only 10 per cent less than this, showing conclusively that the majority of

irrigators were using nearly their full allowance of water; or, in other words, were wasting very generously.

Mr. Long was not trying to economize; yet during the period of greatest demand, the months of July and August, he used but 71 per cent of the water he had paid for. With this margin to his credit, but his water bill the same at the end of the season whether he draws on it or not, the average irrigator is not likely to economize in the use of water.

The ditch manager in the meantime is taxing the strength of his ditch banks to divert water, a large percentage of which returns to the river without having done any good, but in many cases has actually damaged valuable land. As a result of the present low duty of water in the Boise Valley nearly all the large canals must be enlarged to nearly three times their present capacity—either enlarged or the duty of water increased. Their enlargement means a further investment of many thousands of dollars; the duty of water can be raised by changing the present system of its distribution to the irrigators, which will cost practically nothing. This latter course will not only render unnecessary the further investment of capital in some of these canals for many years, but will effect a great saving in expense to every careful irrigator, besides doubling the water supply of the valley.

In Mr. Goodwin's case we find the conditions just reversed—a water contract providing for a duty of water nearly three times as great as has been attained by the irrigators. The Payette Valley is particularly blessed in its water supply, therefore no reason existed for assuming that it would be used sparingly. Yet we find here a water contract entered into providing for a very high duty of water without containing a single provision that would enable the user to attain such a result.

The investor has been bitterly disappointed as a result of this blunder, for the capacity of the works which furnish water to Mr. Goodwin was based upon this assumed duty, only one-third of which has been attained in their operation. Another canal in the meantime has been built to supply the deficiency, that will furnish water to more than one-half the territory for which the first canal was intended.

Had the water contract, however, provided for the delivery of irrigating heads in turns to users, the cost of such service based upon the quantity of water delivered instead of the continuous flow of a specified volume to be paid for by the acre, it would have been in harmony with the necessities of the irrigators; the distribution of the water would have been under the complete control of the company, all the waste being thus prevented; and a very high duty might easily have been attained, and that with the hearty cooperation of the users, while a large investment, now nearly a total loss, would have been placed upon a paying basis.

WASHINGTON.

USE OF WATER IN IRRIGATION IN THE YAKIMA VALLEY.

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INTRODUCTION.

This report of necessity can cover but little more than the distribution and methods of using water in irrigation in the Yakima Valley. At any rate, it would be well to know something of the practice before discussing duty, for practice will always be a large factor in determining duty. To find out how water is used on the several crops raised in the valley, lists of questions were prepared and submitted to farmers who are successful in their several specialties. These questions were not only very fully answered, but many valuable suggestions were offered. The writer wishes to extend thanks to that very large number of persons who have not considered it any trouble to answer questions by mail or by personal interview.

Almost no data are given concerning the large crops and phenomenal yields of the valley. To one who has been over the valley there is no need to report yields; by those who have not seen it for themselves such reports would not be believed, so they are omitted.

The first intention was to confine all investigations to the plant at Prosser, where the conveniences for making measurements were very kindly offered by Hon. Levi Ankeny, president of the company, and Mr. E. F. Benson, general superintendent. Mr. John Chisholm, their local superintendent, assisted in making measurements and also collected much helpful data. Later inquiry developed the fact that among the records of the Yakima Investment Company were to be found the gage heights of the canal at the headgate for the last five years. The company's engineer, Mr. J. L. Stackhouse, kindly assisted in rating the canal. With this data at hand it was possible to make up the

general duty for 1898, 1899, and 1900. Consequently the work of the department was extended to the Sunnyside Canal. Here the company, through their general superintendent, Walter N. Granger, offered valuable assistance in gathering data. Without the statistics furnished by the company the report of conditions under the Sunnyside Canal would have been very meager.

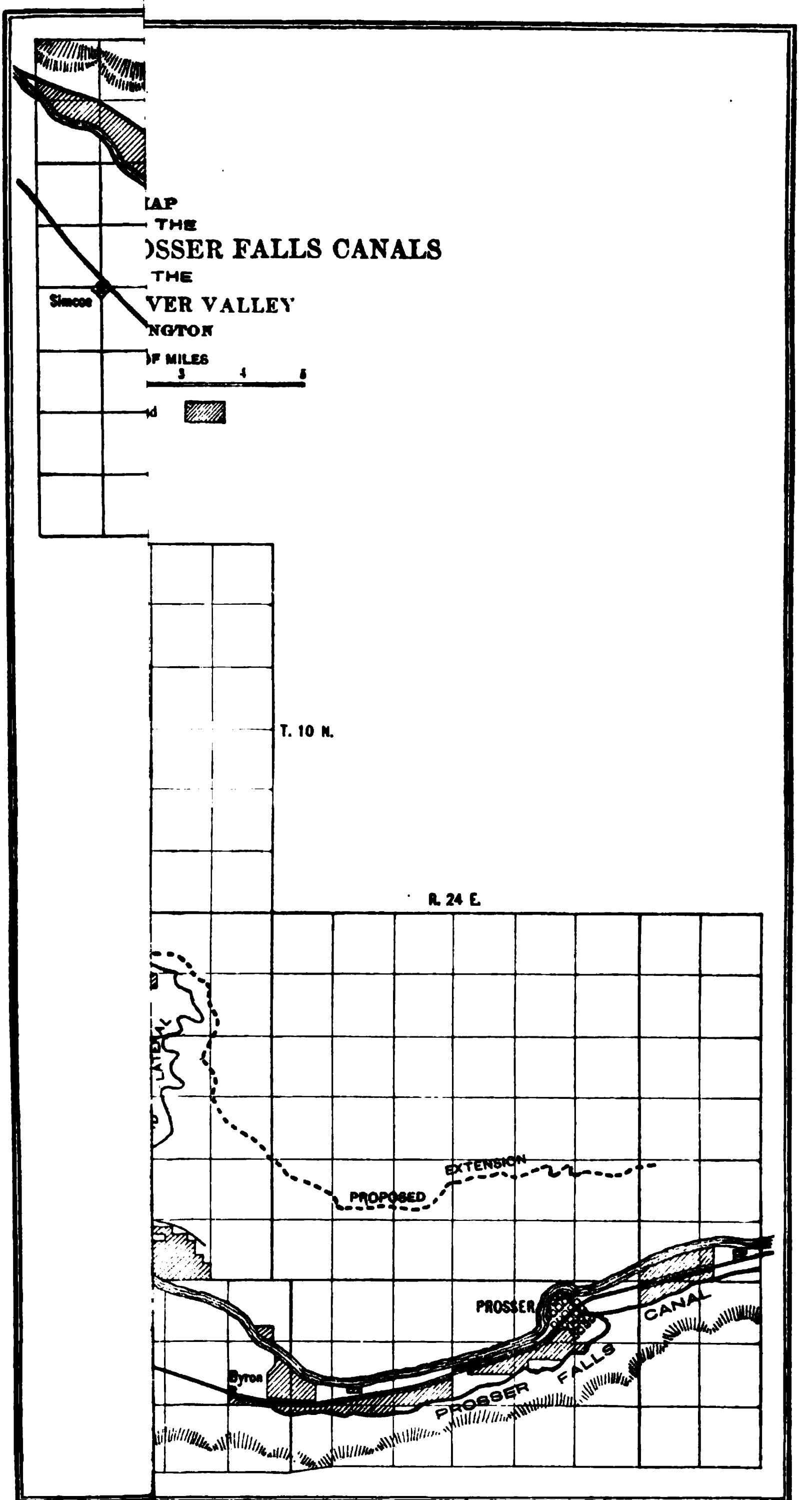
The work will be continued during 1901 both at Prosser and at Zilla. An effort will be made to determine losses by seepage from both canals and also to find the duty for several varieties of crops. In the latter cases the water will be measured at the point of application, so as to eliminate any losses in transit.

SOIL.

The cultivated valleys of the Yakima consist of ancient lake bottoms. Ellensburg is near the center of the upper one. The second is crossed by the Natches River and Wenas Creek and includes Selah Creek Valley on the east. The next one includes the Moxee west of the Yakima River and is crossed by the Ahtanum and Cowiche creeks. The city of North Yakima is located in the upper part. The last of these valleys is the one in which are located Sunnyside and Prosser ditches. Toppenish and Satus creeks cross it from the west (see map, fig. 27).

The elevation of North Yakima is 1,078 feet and of Prosser 674 feet.

The Yakima, one of the largest rivers in Washington, rises in the Cascades, near the center of the State, and flows southward to its junction with the Columbia, 15 miles above the forty-sixth parallel, which separates this State from Oregon. After passing through the last spur of the mountain system, where it receives the water of the Natches and the Ahtanum, it flows some 80 miles in a wide valley which was once a part of the great lake the Columbia drained when it broke through the Cascades and out to the ocean. The soil is therefore of great depth and fertility. The pitch of the valley being so slight, the silt remained in place when the lake receded and the present water courses were established. The soil deposit of disintegrated basaltic rock ranges from 6 to 80 feet deep and forms the soil of all the irrigated lands. Low down by the streams it is somewhat alluvial; upon the benches it consists of the undisturbed lake deposits. It is sufficiently porous to readily absorb the water and allow a free penetration of plant roots. In places where its depth is exposed for considerable distance, as at Zilla, where the river has cut down its bank, the soil is 80 feet deep, and wherever wells have been sunk the soil has been found to be from 60 to 100 feet in depth. The extraordinary depth of this soil would seem to be sufficient assurance of its permanent fertility.



IAP
THE
)SSER FALLS CANALS
THE
VER VALLEY
NGTON
)F MILES
3
4
5
Simcoe
T. 10 N.
R. 24 E.
LATERAL
PROPOSED
EXTENSION
PROSSER
Byron
PROSSER
FALLS
CANAL

The following table shows the chemical analyses of average specimens of the soil. These analyses were made by the department of chemistry of the State Agricultural College.

Analyses of Yakima soils.

	No. 1.	No. 2.	No. 3.	No. 4.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Insoluble residue	....	76.780	78.4340	....
Insoluble silica	64.860	71.670	60.2070	67.5283
Combined silica	10.185	5.110	18.2270	11.9390
Soluble silica	.385	.180	.2100	.1732
Potash	.700	1.070	.4328	.7867
Soda	.700	.350	.3739	.1432
Lime	1.448	2.000	1.2127	.4355
Magnesia	.991	1.340	.7880	.2585
Peroxid of iron	4.768	6.880	5.1586	1.3009
Alumina	6.238	7.910	6.8906	7.9041
Phosphoric acid	.224	.130	.1007	.1008
Chlorin	.014	Trace.	.0058	.0181
Sulphuric acid	.129	.020	Trace.	.0378
Water at 120° C	1.125	1.510	3.4527	3.0800
Volatile and organic matter	2.600	1.310	3.0195	6.4805
Total	94.367	99.480	100.0798	100.1866
Humus	....	4.100	.2550	....
Nitrogen	....	....	.0876	....

No. 1 was taken from the Lower Yakima country, 8 miles southwest of Kiona; No. 2 from the Ahtanum Prairie, southwest of Yakima; No. 3 from the Wenas Valley, 6 miles north of the city; No. 4, from Fremont, Nebr., is placed in the tables for comparison.

A comparison of these soils shows that those of the Yakima country are especially rich in lime, potash, and phosphoric acid, the three constituents most essential to plant life. In this the soil is in no way exceptional to all basaltic soils wherever found. They are characteristic soils of Italy and southern France. In Arizona and Mexico, where land has been under cultivation since the Spanish conquest, the basaltic soil still retains its marvelous fertility.

In the desert state this land is covered with rank sagebrush, and in some places coarse bunch grass grows with it. The surface is densely packed. However, the crust is easily broken by the plow, and underneath the soil is almost as light as ashes, though compact and hard farther down, so that wells stand without curbing, except for a little distance at the top. When once subdued it requires very little cultivation to keep it soft and friable. The land under the Sunnyside Canal throughout its whole extent is especially adapted to the growth of hops, alfalfa, and the larger fruits, as well as sweet potatoes, sweet corn, peanuts, sorghum, apricots, and grapes. On account of its long arid condition the land lacks humus which can be supplied only by the decay of animal and vegetable matter. This valuable constituent of the soil can be increased from year to year by the addition of barnyard manure and straw and by turning under cover crops or green manures, etc. The raising of strong, deep-rooted plants assists very greatly.

Russell says:

The soil through central Washington is deep and rich, with the exception of precipitous mountain slopes and certain and fortunately limited portions of the valley where it is too alkaline, and is well adapted to agriculture. Owing to the small rainfall the general appearance of the country is barren and sterile, yet where irrigation is practicable the harvests are unusually abundant. The principal crops are hay, alfalfa, wheat, oats, potatoes, hops, and fruits and vegetables of many kinds. The weeks and months of uninterrupted sunshine during the long, hot summer admit of an almost tropical luxuriance of plant growth when the required moisture is supplied. However, only a small percentage of the entire area can be economically irrigated from surface streams.

On the high plateaus, many of which have unusually rich soil derived from the decay of volcanic rocks, and on the lower and very gentle mountain slopes bordering many of the valleys, there are large areas of fine land which are beyond the reach of all ordinary irrigation methods, and must be reserved for grazing. This soil is a fineloam, deposited by lake sedimentation, and on Sunnyside is from 30 to 120 feet deep. When kept well cultivated it has a wonderful water-holding capacity. The adjoining hills are mostly basalt rock, and the soil comes from the decomposition of this country rock, with possibly some volcanic ash. The soil is short in humus, but on account of the very large amount of alfalfa grown and fed on the ground this constituent in time will be supplied. The upper layers of this soil have undoubtedly been modified by material carried in and deposited by the wind. Such soil would likely carry an excess of clay and could be well irrigated by small streams, as is the case in the Yakima Valley.

This soil bakes when flooded, and consequently the old flooding system has been largely abandoned to give place to furrow irrigation, which seems to be well adapted to the soil. Irrigation tends to compact the soil. There is always a running together of the particles, the smaller ones silting into the openings between the larger grains. Consequently the ground becomes closer, more compact, and when dry very much harder. A second or third watering through the same old furrows will be very much slower, and not so complete.

CLIMATE.

The climate of the valley is shown by the following tables giving precipitation, temperature, evaporation, etc., at Sunnyside and at Prosser:

Climatic data for Sunnyside, Wash.

Month.	1896.			1897.			1898.			1899.			1900.		
	Precipitation.	Mean temperature.	Clear and partly clear days.	Precipitation.	Mean temperature	Clear and partly clear days.	Precipitation.	Mean temperature	Clear and partly clear days.	Precipitation.	Mean temperature.	Clear and partly clear days.	Precipitation.	Mean temperature.	Clear and partly clear days.
	In.	*°F.*		*In.*	*°F.*		*In.*	*°F.*		*In.*	*°F.*		*In.*	*°F.*	
January	1.44	32.6	20	0.83	30.8	6	0.40	27.9	18	2.08	28.4	14	0.57	35.6	22
February	.17	41.4	24	.88	35.7	16	.14	41.4	19	.50	30	20	.45	34.6	11
March	.20	41.9	26	.25	39.3	22	.05	42.5	29	......	42.8	23	.47	48.4	24
April	.51	48.8	17	......	55.3	25	.05	52.3	23	.12	50.8	23	1.01	52.6	23
May	.58	56.4	26	.20	64.3	26	.73	59.2	24	.62	55.6	23	.46	60.2	21
June	.14	66.6	27	.30	67.8	19	.49	66.6	23	.11	64.2	25	.21	68.8	25
July	......	77.3	30	.47	69.3	30	......	72.4	28	......	73.7	29	.10	72	31
August	.71	72	27	.21	74.4	27	.07	75	27	.60	65.2	23	.26	66.2	28
September	.40	61.4	25	.21	59.9	22	.52	62.8	27	.30	64.7	24	.72	60.2	23
October	.42	51.2	28	.11	49.4	27	.11	49.6	24	.89	49.4	20	.60	49.6	17
November	1.49	30.2	13	3.03	39.3	8	.41	38.2	12	1.84	46.6	6	......	......	......
December	1.93	36.1	6	1.61	32.2	9	.06	27.2	17	.66	34.9	10	......	......	......
Annual	8.05	51.3	267	8.10	51.5	237	3.03	51.4	270	7.72	50.5	153	......	......	......

Rainfall at Prosser, Wash., 1900.

	Inches.
May 11	0.13
May 16	.12
May 26	.16
	.41
June 23	.24
June 24	.90
	1.14
August 23	.30
September 7	.13
September 17	.33
	.46
October 5	.34
October 19	.40
October 24	.11
	.85
Total for season	3.16

Evaporation at Prosser, Wash., 1900.

	Inches.
May 9–21	1.5
May 21–June 3	2.4
June 3–June 17	3.1
June 17–July 1	2.3
July 1–July 14	3.2
July 14–July 30	3.5
July 30–August 13	2.7
August 13–September 17	3.6
September 17–October 1	1.3
October 1–October 29	1
Total	24.6

WATER SUPPLY.

The situation of Yakima County so near the slopes of the Cascade range possibly provides a more abundant supply of water than is enjoyed by any other irrigated section in the West. The enormous rain and snow fall upon the mountains gives rise to a large number of small streams which meander down the watershed with rapid fall, to join the swift currents of the Yakima and Natches, which in turn descend at the rate of 30 to 40 feet to the mile. By reason of this steep grade of the natural water courses the irrigating canals draw rapidly away from the streams, and with a minimum of length and expense, reclaim a maximum of land. The slope of the bluffs inclosing the valleys being for the most part gradual, the difficulties of construction are correspondingly decreased. These conditions of an

abundant water supply and its economical development have promoted irrigation enterprises and hastened the settlement of the country. The pioneers, attracted by the ease of the undertaking and the promise of rich results, dug small ditches and reclaimed small tracts along the rivers. For many miles the results of their labors may be seen in beautiful fields and orchards. Following them came the canal companies with ample means, and the work which was accomplished by the pioneers on a limited plan has been advanced on a broad scale by the latter, and there now exists a continuous line of irrigation systems from Kennewick to the Selah Valley.

The Yakima River drains the eastern slope of the mountains. The following table, compiled from reports of the United States Geological Survey, shows the average discharge of the Yakima River at Union Gap for the months of August, September, and October for the years 1897, 1898, and 1899. It also shows the minimum discharge during each of these months at the same point:

Discharge of Yakima River at Union Gap, Washington.

	1897.	1898.	1899.
	Cu. ft. per sec.	*Cu. ft. per sec.*	*Cu. ft. per sec.*
Average discharge for August	1,141	1,365	3,111
Minimum discharge for August	885	885	2,170
Average discharge for September	771	885	1,704
Minimum discharge for September	685	785	1,430
Average discharge for October	785	1,833	1,680
Minimum discharge for October	685	685	1,200

A gaging at Prosser Bridge August 12, 1900, showed a discharge of 620 cubic feet per second.

It will be noted that the minimum discharge for the irrigation season runs as low as 885 cubic feet per second in August for both the years of 1897 and 1898. The 620 cubic feet per second rating was taken many miles lower down and below the intakes of all the canals. It was generally agreed that the water was lower during August of 1900 than had ever been known before. This, however, can only be a guess until the gage heights at Union Gap are published by the United States Geological Survey. If the duty is figured at 160 acres per cubic foot per second and no allowance made for losses from seepage or evaporation, this amount of water would irrigate 141,000 acres of land. At a 120-acre duty it would supply 106,000 acres. And at a 100-acre duty, the amount allowed by the new ditch from the Moxee, it would supply 88,500 acres.

There are already projected canals to divert water from just below Union Gap sufficient to much more than use the total flow at low water even at a 160-acre duty. It is probable that if all lines now surveyed should be constructed and all tributary lands should be put under cultivation the flow from the latter part of July and on to

November 1, losses of all kinds considered, would only half supply the demands placed upon the river.

Judging from the way water is now used along the Yakima, including losses, it would require about four times the average flow of the river for the months of August, September, and October to supply the ditches in service and those projected. These estimates are based upon the published reports of the irrigation companies and the United States Geological Survey. These figures are not designed to alarm anyone, but in discussing the subject of irrigation of the Yakima Valley there is a disposition to assume that there is no limit to the water supply and that this region is different from any other in the world, in that no care and economy need be exercised. The aim of the writer is only to call attention to the fact that if all the canals now mapped out should be completed their large claims to water would never be realized. This condition of affairs is by no means peculiar to Washington. It is the common history of irrigated districts. Had the water been sold at so much per cubic foot per second, or per acre-foot, or even by the miner's inch, on the same basis as the land, a different condition of affairs would prevail. The millions of dollars spent in litigation over water rights would have been saved.

PROSSER FALLS IRRIGATION SYSTEM.

The streams of Yakima County forming the basis of the water supply do not, as is so frequently the case in irrigated countries, flow through deep canyons or rocky gorges, thus rendering it a matter of great difficulty to obtain water from them. Gravity alone is necessary in most cases to divert the water from the river and to spread it over the land. The canal of the Prosser Falls Irrigation Company is the one exception to this rule. As the name of the town and company would indicate, the Yakima River has here a fall. The fall is 20 feet in a half mile and during the dry season in October of 1900 the river discharged 620 cubic feet per second, capable of producing 1,400 horsepower. A portion of this power is now utilized to elevate the water required to irrigate the land on the south side of the river, which is too high to be supplied by a gravity system.

The system has been in operation for several years, and at present the company has a canal that irrigates 1,641 acres, extending 11 miles along the river and railroad and including the streets and gardens of the town of Prosser.

The headworks, which are placed in the rocks on the south side of the river, are made of 10 by 18 timber, are 22 feet high and 36 feet wide, with six openings for gates, each 4 feet wide in the clear. A temporary wing dam extends from the headgates into the river to divert the current into the flumes. The water is discharged into two flumes, each 10 feet deep and 12 feet wide. The water is 5 feet deep in the flumes when the river is lowest. One of these flumes supplies

water for a flour mill; the other supplies power for the pumping plant.

From the headgate to the power house is 650 feet. Part of the fall is lost during high water, and the machinery has been designed for a 12-foot fall. The water from the fore bay enters a flume 10 feet wide, 17 feet deep, and 65 feet long, and from the flume enters three penstocks, from which it is discharged through the turbines.

The turbines are 48-inch special Victors and develop 135 horsepower each, under a 12-foot head. Each turbine drives a duplex power pump, 25-inch cylinder, 22-inch stroke. Each pump has a capacity of 4,000 gallons per minute. This is the discharge at an 80-foot per minute piston speed, and the pumps can, when necessary, be worked at a 100-foot piston speed. Two pumps and two turbines are in successful operation, and when working at their highest efficiency will furnish 18 cubic feet per second, which at the duty of 140 acres per cubic foot per second would irrigate 2,500 acres. When the third pump is in; the plant will have a daily capacity of 17,800,000 gallons, or about 27.4 cubic feet per second.

From the pumps the water passes through 1,800 feet of 28-inch steel pipe to the penstock at the head of the company's canal. Three hundred feet from the penstock the canal divides into two branches. The west branch is 8 miles long; the east branch is now 3 miles long. Later it will likely be continued down the river to cover a fine body of land several miles beyond

DITCHES.

These ditches show every evidence of having been aligned by the man with the scraper. In places the grade is so light that the stream is very sluggish, necessitating constant labor to keep it free from weeds, while at other points the grade is so heavy that the bottom and sides are scoured clean of any silt, causing considerable loss from seepage.

The upstream branch is high above the irrigated land where it leaves the flume at the end of the pipe line. In places the bottom and sides have scoured so that it has become necessary to insert drops. There is only one short flume of any importance on the line. At times the grass and weeds check the flow so that in places the water level is raised as much as 6 inches. This usually causes trouble, necessitating the raking out of the weeds and the frequent repair of the banks.

The downstream branch for most of its length has a rapid current. It runs over gravel, and at first had to be silted to make it carry water at all. This branch, for the most part, is free from weeds.

The soil under the lower ditch is shallow and is underlaid by a deep bed of coarse gravel. Something of the character of the subsoil along this ditch can be seen by a visit to the Northern Pacific gravel

pit, which lies under it. At this point there is from 18 to 36 inches of soil liberally mixed with fine gravel and very fine sand. Below this there is no well-defined hardpan. What there is will be found in broken layers. There are pockets of very coarse gravel, ranging from the size of a pigeon's egg up. In this gravel there is no fine material. It was evidently deposited by the swift-running water. These gravel pockets are so very porous that they would hold large quantities of water should it break through the surface. One farmer said he could dig a hole to the gravel and turn the water for 40 acres into it and the water would all disappear from sight. In all this region the surface soil puddles and forms a fairly good ditch lining.

Under the upper ditch the soil is much deeper, ranging from 3 to 16 or more feet in depth. The wells along its line show soil, fine gravel, then what is called alkali layer, gravel, then clay, under which water is found. The water level in the wells rises some during the irrigation season, and the water becomes alkaline and is not much used for domestic purposes. The soil is very light and, when first put under water, is very thirsty. Small streams rapidly sink out of sight, the soil being too porous to carry them. A rotation system of taking water might be of advantage. Water could then be put on in larger quantities and by traversing the furrows more rapidly would give a more even wetting. At present the water does not reach the lower end of the furrows in sufficient quantities to secure the best results.

When sufficient care is exercised to secure an even distribution the crops are very large. In 1900 one 25-acre tract of alfalfa yielded, by weight, 75 tons from the first cutting, 60 tons from the second cutting, and 50 tons (estimated) from the third, or an average of 7.2 tons per acre.

LOSS BY SEEPAGE.

While it was not possible to determine the loss by seepage from the canal, it was thought desirable to make some determinations on the laterals. Consequently, on October 31, a small stream taken from the receiving flume at a point near to the penstock was measured, and again 1,190 feet farther down. This was about such a stream as had been allowed to run during the summer to supply a small part of Prosser. The measurements were made over a 45-degree triangular notch with conditions, as to contractions, the very best. This stream had a fall of about 75 feet in 1,190, so it did not have much time to sink into the ground. Water that came so near standing on end as this did would not be expected to lose so much from its volume as it would if it were more sluggish and a longer time were required to get the same quantity past. Yet, under these conditions, the loss was 25 per cent of the quantity entering the lateral. The ground crossed by this lateral was gravel.

Measurements were also made on a lateral from the lower branch of the canal. This ditch had been out of service for four days. However, the weather had been damp and rainy most of the time the ditch had been empty. Its banks were moist and showed no cracks; in fact, a small part of it was flume, and the flume showed no leaks. The water was measured over a Cippoletti weir about 400 feet from the main ditch and again 2,000 feet farther down. The velocity of this stream was all the banks could stand and not scour. The first measurement showed a flow of 0.50 cubic foot per second, while the lower measurement showed only 0.18 cubic foot per second, a loss of 0.32 cubic foot per second, or 64 per cent of the original amount. The ground over which most of this stream was carried was coarse gravel, covered only by a thin layer of soil, say from 4 to 9 inches deep. While enough water for 60 acres was delivered, only about enough for 17 acres was received at the point of distribution. From this point it had been run through long furrows and had been lost before the lower ends were reached, as was shown by the burned condition of the crop. This condition at the lower end of the long furrows can be found in a good many places under the Prosser ditches, and is accounted for largely by losses from water running long distances through a light, ashy soil and over a gravel subsoil.

The same conditions of surface and subsoil prevail over most of the irrigated land along the lower branch of the canal. It is hardly possible to avoid this loss unless flumes are substituted for the open ditches. They could be made to save nearly all the water now lost in transit. Further, the furrows should be fed from head ditches or flumes at short intervals. This would bring all the water measured to the consumer directly to the growing crop and minimize the losses from seepage. However, it is very apparent to a casual observer that the method of allowing a continuous flow of 3 inches for 10 acres is a vicious plan. It is only necessary to consider the soil at Prosser and the action of such a small head to see that it will never be satisfactory. If sold by the inch, the charge should be a stipulated amount per twenty-four hour inch, or so much per acre-foot. Then, instead of a driblet the irrigator would have a larger volume turned into his ditches at stated intervals. Suppose the farmer got a forty-eight hour service every two weeks; then he would be entitled to 21 inches for the time of using it. This would be a good irrigating head and would be carried up by the soil, thus saving a large percentage of the present loss.

DUTY OF WATER AT PROSSER.

Investigations at Prosser commenced in May of 1900. The register used in this work was not there and set up for use until August of 1900.

At the outlet of the pipe line is a penstock and a flume. The flume

is 100 feet long by 6.76 feet wide by 3 feet deep. In the early part of the season, when the ditch was clear from vegetation, this flume was selected as a gaging station, but on account of the vegetation in the ditch immediately below the ratings were so erratic that no reliance could be placed on daily rod readings. A new point was selected, but to prepare it and to install a register would entail shutting down the pumps for two or three days, which was not thought advisable in August, when the register was ready for installation. So it was set on the flume, and the ditch superintendent, having learned the details of its operation, will be able to give good service next season when the instruments are in their new location.

However, the company placed automatic registers on their pumps shortly after starting in April. After some observation, it was determined to rely upon the data furnished by the pump registers. This record has been very well kept, and seems to be fairly reliable. The readings have been recorded several times each day as an evidence to the superintendent of the speed at which the pumps were being run. Estimates were made that seemed to indicate that 10 per cent for loss in the pumps by slippage would be ample to cover all waste from that source.

The following table gives the depths to which the water discharged by the pumps each month would cover the 1,641 acres irrigated:

Depth of water supplied by Prosser Canal, 1900.

	Feet.
April	0.36
May	.43
June	.45
July	.62
August	.45
September	.40
October	.33
Total	3.04

The smaller part of the 1,641 acres was under a contract for a duty of 120 acres per cubic foot per second; the remainder was to be served at the rate of 160 acres per cubic foot per second. The actual average duty for the year was 140 acres, water measured at the pumps after a 10 per cent loss for slippage had been deducted. This, possibly, was more than the actual waste from that source. From the pumps to the receiving flume there was no loss, water being carried 1,800 feet in a steel-riveted pipe. No investigations were made upon which to calculate the loss from seepage in the main canal. As much of it runs over gravel and must rely upon silt to make the channel water-tight, it is likely that considerable loss followed from this source. No determination of this loss was made, and it is not worth while to offer a guess as to its amount.

The evaporation at Prosser, as given above, was 24 inches for the

season. Making this deduction from the total water surface in the canal and allowing one-half as much more for loss from the laterals, the probable loss from this source would not be more than 0.2 of an inch over the whole area irrigated. This loss would be less than 0.5 per cent of the total amount of water supplied, and consequently may be disregarded. This, of course, does not include the evaporation loss from furrows during the time they are in service. No doubt this loss is considerable when water is turned onto hot ground under a blazing sun.

The amount of loss from laterals has been discussed under another head, the two measurements made showing losses of 25 and 64 per cent, respectively. With such widely varying results on laterals and no measurements on the main canal, it is useless to make any estimate of the total loss from seepage before the water reaches the land, although it is known to be very heavy. Leaving this loss out of account, we have the following statement of the duty of water under the Prosser Canal:

Duty of water under Prosser Canal, 1900.

Area irrigated	acres	1,641.00
Depth of water used in irrigation	feet	3.04
Rainfall during season	foot	.26
Total depth of water received by land	feet	3.30

THE SUNNYSIDE CANAL SYSTEM.

The Sunnyside irrigation enterprise is one of the largest in the United States and the largest in the Northwest. The canal is 41.78 miles in length, covering, by means of 250 miles of branch canals and laterals, an area of 40,000 acres. It is surveyed and located for 18.22 miles additional, and this extension will be constructed when the area now covered is settled up. This extension will cover 24,000 acres, making a total of 64,000 acres under the completed canal. The canal is complete in every respect, the excess water being turned back into the Yakima River at a point about 18 miles above what will be its permanent outlet when the remaining 24,000 acres are put under water.

The canal takes its supply of water from the Yakima River at a point on the left bank of the river, 7.5 miles below North Yakima. Here a dam and headgates have been constructed. The canal has a bottom width of 30 feet, top width of 62 feet, and depth of 8 feet, with side slopes of 1 foot on 2. The grade is 15 inches in 5,000, and its initial capacity is 750 cubic feet of water per second. The company's claim to water from the Yakima River is 1,000 cubic feet per second.

The Sunnyside irrigated district begins at the rich Parker bottom, 8 miles down the Yakima River from North Yakima, and extends along

the north bank of the river for 50 miles, terminating at Prosser. It is part of the broad area of bench land through which the Yakima River flows for 85 miles after passing Union Gap. The lands reclaimed by the Sunnyside Canal border the Yakima River for 50 miles in an oval-shaped tract, having an extreme width of 8 miles. This territory is readily accessible to the Northern Pacific Railway, which parallels the river's west bank. The terraces and benches are admirably varied, pleasing the eye, affording locations suitable for different crops, and insuring successful irrigation. The slope is southeasterly toward the river and in the direction of its current. This slope is just enough to receive water to the best advantage. The land has a direct exposure to the forcing rays of the sun, and for this reason it was appropriately named the "Sunnyside." The surrounding hills form a broad-surfaced circular barrier on the west, north, and east sides, shielding the valley from the winter winds.

PREPARING LAND FOR CULTIVATION.

The cost per acre to clear, grade, and place water upon land in Sunnyside is about $12.50. This places the land in condition for cropping. The Sunnyside section is covered with a dense growth of sagebrush. This can readily be removed with a mattock, a good worker being able to grub an acre per day. The sagebrush is used for summer fuel or is burned or placed upon the highway, making a dustless road. After the removal of the sagebrush the land is plowed, and the high knolls are cut down either with an ordinary scraper or with a so-called buck scraper to which four horses are hitched. The buck scraper is a useful invention for the leveling of the ground for the purpose of irrigation, and small knolls or hummocks are cut down by means of a scraper resembling that used for scraping highways in the Eastern States. A leveler or planer is also used. This planer consists of two long timbers with six cross pieces which catch the higher points and carry the earth into the lower places.

METHODS OF DISTRIBUTION.

Measuring boxes.—The measuring boxes on the Sunnyside Canal show considerable variety in shape. Some of them are made after the principle of the Foote box. The slot is 2 inches high and is cut out of plate iron. The brim is perfectly contracted. The head on top of the slot is 6 inches. An overfall, made of a plate of iron, and usually extending the length of the box, is provided. The headgate is raised until the water just starts over the overfall and is then locked. So also is the slide which adjusts the length of slot. In most instances the headgate opening is about 2 feet below the level of the water in the canal, so that slight differences in water levels do not materially modify the discharge. Some of the measuring devices consist of a Cippoletti weir with an iron overfall at proper elevation.

The company's engineer has been very particular in making and setting the measuring units to have everything substantial and fixed so that they will require a minimum of repairing. The velocity is very slow in the boxes and the contraction is generally perfect. They can generally be relied upon to give good service. The water is delivered in large quantities and continuously, so that the farmer may run it as he pleases and soak the ground thoroughly.

METHODS OF APPLYING WATER.

Practically all the irrigation in the Yakima Valley is done by the furrow system. This consists of marking or furrowing land to be irrigated with shallow furrows about 3 feet apart. In some instances they are made 4 feet apart, but in that event the ground between the furrows does not show complete wetting, as is evidenced by the weaker growth of plants in the middle between the rows and in some instances the drying up of vegetation entirely. In some cases, where the land is being seeded to alfalfa or clover, the furrows are made only 18 inches apart and the middle ones are abandoned after the crop is well set and the ground covered. The furrows are generally made on a gentle slope or placed on contour lines. They should always depend on the slope of the ground and never depend upon the fence lines for their direction. The upper ends of the furrows are led to a head ditch or flume from which the water is discharged into them and allowed to follow down their course until the ground is thoroughly and evenly wet. The amount of water to be turned into any furrow depends upon its slope and the capacity of the soil to absorb it. As a rule, enough should be turned into the furrow to run its entire length without washing or cutting. To avoid this the water should not run muddy. About one-ninth of an inch under a 6-inch head, or about one-three-hundred-and-sixtieth of a cubic foot per second, should be able to make about 3 feet along the furrow in a minute. This would be approximately 1 gallon per minute. If the water requires twenty-four hours to reach the lower end of a square 10-acre tract, or runs only 40 rods in twenty-four hours, the system is regarded as working well. When the grade is pretty flat and the soil light, more water will be required to give such a velocity.

The water is turned from the head or supply ditch into furrows through small pipes or spouts, made by nailing four laths together with 3-penny nails. One end is run through the bank of the ditch and the other extends to the furrow. The flow is regulated by placing a button over the end of the spout. In some cases the banks of the head ditch are sodded over and the furrows taken directly from it, thus dispensing with the lath pipes. This is practicable only where the soil is not likely to wash. In some places head flumes set on steep grades and made to deliver water on both sides are used. When the

grade is steep, cleats are nailed diagonally across the bottom of the flumes to check and direct the water to the openings. In such cases the head on the openings is slight but is compensated for by the high velocity of the water in the flumes.

The soil of the Yakima Valley seems well adapted to the furrow system. Other methods have been tried, but in most instances have been abandoned. Land irrigated in this way is easy to work over. It requires the removal of no large bodies of earth when the system is first installed, and needs only to be graded to an even sloping surface. Depressions are filled and knolls are cut down. If the land has been carefully graded and as carefully furrowed the water will need little attention. Consequently, the system is cheap. The ground is thoroughly soaked without wetting the surface. The surface not being wet, evaporation is slow and cultivation can be commenced soon after watering. The length of the furrows should depend very much upon the character of the soil, whether it will carry up a stream or not.

DUTY OF WATER UNDER SUNNYSIDE CANAL.

As was stated in the introduction, the Sunnyside Canal Company has records of the water entering its canal for several years past. However, the records of the areas irrigated are available for the last three years only, so that the duty can not be calculated farther back than 1898. The following table gives the areas in various crops under the Sunnyside Canal for the years 1898, 1899, and 1900:

Acreage of crops under Sunnyside Canal.

Name of crop.	1898.	1899.	1900.
	Acres.	*Acres.*	*Acres.*
Alfalfa	3,061	4,355	5,842
Clover, clover and timothy	232	689	1,318
Alsike and timothy	....	45	45
Timothy	....	30	47
Blue grass	....	....	19.5
Brome grass	....	....	2
Corn	709	512	495
Potatoes (Irish)	275	145	367
Potatoes (sweet)	....	....	.5
Watermelons	16	60	35
Muskmelons	....	5	15
Orchard	1,820	1,848	1,991
Hops	372	392	380
Beans	16	8	26
Peas	8	10	25
Wheat	258	264	241
Berries	9	12	17.5
Tomatoes	3	4	2
Cabbage	1	3	4
Artichokes	8	10	15
Grapes	6	10	8
Carrots	22	25	8.5
Sorghum	25	20	10
Onions	4	3	6.5
Barley	10	5	....
Peppermint	5	....	....
Garden	23	42	26.5
Total	6.883	8,497	10,947

The following tables show the water received by these areas for the three years:

Daily discharge of Sunnyside Canal, 1898.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	85.2893	253.8843	293.5537	382.8099	571.2396	503.8016	313.3884
2	85.2893	253.8843	293.5537	442.3140	604.9587	503.8016	313.3884
3	95.2066	253.8843	293.5537	537.5206	636.6942	503.8016	313.3884
4	95.2066	253.8843	293.5537	537.5206	636.6942	503.8016	313.3884
5	111.0744	253.8843	293.5537	537.5206	636.6942	503.8016	313.3884
6	111.0744	253.8843	293.5537	537.5206	636.6942	503.8016	313.3884
7	124.9587	253.8843	293.5537	537.5206	636.6942	503.8016	313.3884
8	124.9587	253.8843	293.5537	472.0660	636.6942	503.8016	313.3884
9	140.8264	253.8843	313.3884	442.3140	636.6942	501.8182	313.3884
10	140.8264	253.8843	313.3884	604.9587	636.6942	442.3140	313.3884
11	140.8264	253.8843	313.3884	537.5206	636.6942	442.3140	313.3884
12	158.6777	253.8843	333.2231	571.2396	636.6942	442.3140	313.3884
13	174.5454	253.8843	357.0248	571.2396	636.6942	442.3140	313.3884
14	174.5454	253.8843	357.0248	571.2396	636.6942	442.3140	313.3884
15	194.3802	253.8843	382.8099	571.2396	636.6942	442.3140	293.5537
16	214.2149	253.8843	382.8099	571.2396	636.6942	410.5785	273.3719
17	234.0496	313.3884	382.8099	174.5454	604.9587	410.5785	273.3719
18	214.2149	313.3884	382.8099	194.3802	604.9587	382.8099	273.3719
19	214.2149	313.3884	382.8099	472.0660	571.2396	410.5785	273.3719
20	234.0496	313.3884	382.8099	472.0660	537.5206	382.8099	273.3719
21	234.0496	313.3884	382.8099	503.8016	537.5206	382.8099	273.3719
22	253.8843	313.3884	382.8099	472.0660	537.5206	410.5785	273.3719
23	253.8843	313.3884	382.8099	472.0660	537.5206	382.8099	273.3719
24	253.8843	313.3884	382.8099	472.0660	537.5206	382.8099	273.3719
25	253.8843	313.3884	410.5785	472.0660	537.5206	382.8099	273.3719
26	253.8843	313.3884	410.5785	503.8016	537.5206	382.8099	273.3719
27	253.8843	313.3884	410.5785	503.8016	537.5206	382.8099	253.8843
28	253.8843	313.3884	442.3140	503.8016	537.5206	357.0248	253.8843
29	253.8843	313.3884	410.5785	503.8016	537.5206	333.2231	253.8843
30	253.8843	313.3884	442.3140	503.8016	503.8016	313.3884	253.8843
31	....	313.3884	....	537.5206	503.8016	....	253.8843
Total	5,587.4381	8,762.9748	10,690.9085	15,187.4360	18,253.8833	10,894.5445	8,957.5037

Duty of water under Sunnyside Canal, 1898.

Area irrigated	acres	6,883.00
Water used	acre-feet	78,334.69
Depth of water used in irrigation	feet	11.38
Rainfall April 1 to October 31	foot	.16
Total depth of water received by land	feet	11.54

Daily discharge of Sunnyside Canal, 1899.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	69.4215	253.8843	410.5785	553.3884	604.9587	503.8016	410.5785
2	69.4215	253.8843	410.5785	537.5206	604.9587	505.8016	410.5785
3	85.2893	253.8843	442.3140	571.2396	604.9587	503.8016	410.5785
4	158.6777	333.2231	410.5785	537.5206	636.6942	503.8016	382.8099
5	158.6777	382.8099	382.8099	537.5206	571.2396	503.8016	382.8099
6	158.6777	410.5785	382.8099	571.2396	571.2396	442.3140	382.8099
7	194.3802	410.5785	410.5785	537.5206	604.9587	472.0660	382.8099
8	194.3802	410.5785	410.5785	636.6942	604.9587	472.0660	382.8099
9	194.3802	426.4463	410.5785	636.6942	666.4463	472.0660	382.8099
10	194.3802	410.5785	410.5785	636.6942	636.6942	472.0660	382.8099
11	194.3802	410.5785	442.3140	....	636.6942	472.0660	357.0248
12	234.0496	410.5785	442.3140	357.0248	666.4463	472.0660	333.2231
13	214.2149	410.5785	456.1983	472.0660	666.4463	472.0660	333.2231
14	234.0496	410.5785	442.3140	604.9587	666.4463	472.0660	333.2231
15	234.0496	410.5785	442.3140	604.9587	666.4463	472.0660	333.2231
16	253.8843	410.5785	442.3140	....	620.8264	472.0660	357.0248
17	253.8843	333.2231	442.3140	....	604.9587	472.0660	273.3719
18	253.8843	396.6942	442.3140	....	604.9587	442.3140	273.3719
19	313.3884	410.5785	442.3140	636.6942	604.9587	442.3140	273.3719
20	253.8843	410.5785	442.3140	666.4463	604.9587	442.3140	273.3719
21	234.0496	410.5785	442.3140	666.4463	604.9587	442.3140	273.3719
22	253.8843	410.5785	472.0660	636.6942	620.8264	442.3140	273.3719
23	253.8843	410.5785	442.3140	472.0660	650.6785	442.3140	273.3719

Daily discharge of Sunnyside Canal, 1899—Continued.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
24	174.5454	410.5785	537.5206	410.5785	650.6785	442.3140	273.3719
25	174.5454	382.8099	537.5206	503.8016	650.6785	410.5785	273.3719
26	174.5454	382.8099	537.5206	636.6942	650.6785	442.3140	273.3719
27	194.3802	382.8099	537.5206	666.4463	650.6785	442.3140	273.3719
28	194.3802	382.8099	537.5206	636.6942	650.6785	442.3140	273.3719
29	194.3802	357.0248	537.5206	620.8264	650.6785	442.3140	273.3719
30	234.0496	382.8099	553.3884	604.9587	650.6785	410.5785	273.3719
31	....	410.5785	....	604.9587	503.8016	....	273.3719
Total	6,000.0003	11,884.9583	13,654.2136	15,548.3464	19,385.2627	13,840.6590	10,058.9253

Duty of water under Sunnyside Canal, 1899.

Area irrigated	acres	8,497.00
Water used	acre-feet	90,372.37
Depth of water used in irrigation	feet	10.64
Rainfall April 1 to October 31	foot	.22
Total depth of water received by land	feet	10.86

Daily discharge of Sunnyside Canal, 1900.

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	194.3802	333.2231	472.0660	636.6942	729.9173	620.8264	410.5785
2	194.3802	442.3140	472.0660	636.6942	761.6529	620.8264	410.5785
3	204.2975	503.8016	503.8016	636.6942	761.6529	636.6942	410.5785
4	234.0496	442.3140	503.8016	636.6942	761.6529	636.6942	410.5785
5	253.8843	472.0660	503.8016	666.4463	793.3884	636.6942	410.5785
6	313.3884	503.8016	503.8016	666.4463	793.3884	620.8264	410.5785
7	333.2231	503.8016	571.2396	666.4463	793.3884	571.2396	410.5785
8	319.3398	503.8016	571.2396	666.4463	793.3884	537.5206	410.5785
9	313.3884	503.8016	571.2396	666.4463	761.6529	489.9173	410.5785
10	333.2231	537.5206	....	636.6942	761.6529	571.2396	410.5785
11	333.2231	537.5206	....	636.6942	729.9173	587.1074	410.5785
12	382.8099	537.5206	333.2231	666.4463	729.9173	587.1074	410.5785
13	410.5785	537.5206	571.2396	698.1818	729.9173	587.1074	396.6942
14	410.5785	543.4711	571.2396	698.1818	729.9173	571.2396	357.0248
15	410.5785	543.4711	604.9587	729.9173	714.0496	537.5206	343.1405
16	442.3140	543.4711	636.6942	729.9173	714.0496	537.5206	357.0248
17	442.3140	537.5206	636.6942	729.9173	714.0496	489.9173	343.1405
18	472.0660	537.5206	644.6281	729.9173	698.1818	489.9173	323.3058
19	472.0660	537.5206	666.4463	729.9173	729.9173	472.0660	313.3884
20	503.8016	537.5206	644.6281	729.9173	729.9173	442.3140	313.3884
21	503.8016	537.5206	644.6281	729.9173	729.9173	442.3140	313.3884
22	472.0660	410.5785	666.4463	729.9173	729.9173	442.3140	313.3884
23	442.3140	234.0496	666.4463	729.9173	729.9173	426.4463	313.3884
24	442.3140	234.0496	666.4463	729.9173	729.9173	410.5785	313.3884
25	410.5785	273.3719	666.4463	761.6529	714.0496	410.5785	313.3884
26	442.3140	382.8099	666.4463	761.6529	698.1818	410.5785	293.5537
27	410.5785	410.5785	636.6942	761.6529	698.1818	396.6942	283.6364
28	357.0248	442.3140	604.9587	761.6529	666.4463	382.8099	283.6364
29	333.2231	410.5785	604.9587	761.6529	650.6785	410.5785	283.6364
30	333.2231	442.3140	636.6942	761.6529	636.6942	410.5785	293.5537
31	....	472.0660	....	729.9173	636.6942	....	293.5527
Total	10,788.0992	14,389.7343	16,109.7514	21,814.2143	22,552.1654	15,387.7074	11.012.5617

Duty of water under Sunnyside Canal, 1900.

Area irrigated	acres	10,947.00
Water used	acre-feet	112,054.29
Depth of water used in irrigation	feet	10.24
Rainfall April 1 to October 31	foot	.28
Total depth of water received by land	feet	10.52

The determinations of duty under the Sunnyside are surprising. After driving over the country and seeing the large amount of water wasted, one is prepared to expect a very low duty. The duty, however, in this region is based on the flow at the intake. Consequently all losses of whatever kind are charged against the land. This, of course, is unfair, and the writer does not for a minute believe that the cultivated lands under the Sunnyside Canal had water poured onto them to the depth of 10.24 feet during the irrigation season of 1900. Yet, with this phenomenal showing, one frequently hears the remark from a rancher, "We do not get water enough."

If lands quite similar in other parts of the State mature a crop on 18 to 20 inches of precipitation, and part of that lost in run off, the question may be fairly asked, What has been done with that very large quantity of water which represents the difference between the amount required and the amount actually supplied by a generous company?

Careful study as to how to distribute and use water will materially change this condition of affairs. Here is a place where studied economy in the use of that which the State gives for the asking will add bounty to the harvests and an income to the Commonwealth.

When the thousands of acres yet to be put under ditch are using water and the flow of the Yakima and its tributaries is taxed to its utmost, and judging from the large increase in population and from the very fertile lands yet to be watered that time is not many years ahead, the present practice will not be possible. The irrigator who has a stipulated amount of water measured out to him will either be obliged to use it with the greatest economy or go out of business.

The evil of the present practice does not end here. The large body of river water comes from the snow-covered mountains and from the melting of deep snow banks. Water from such sources must carry very little fertilizer and almost no humus, a constituent that this soil is especially short in, and one which, as it is slowly supplied by the vegetation grown on the land, should be kept where it is deposited. The use of such large quantities of water tends to leach all this out of the soil.

Professor Heileman, who has spent considerable time studying the alkali conditions of the valley, thinks that old lands should be drained and leached. With the leaching, however, goes many valuable salts as well as detrimental alkalis. On the new land, properly watered, the leaching is not needed to carry away the alkali, and by saving the valuable salts the land will retain its richness much longer. This, if nothing else, will be sufficient reason for careful and skillful irrigation.

There is in the Yakima the tendency that is always found when the water is abundant, to substitute water for cultivation. This disposition is not dangerous at present; the better irrigators and the most

experienced farmers understand fully the value of cultivation. However, fields and orchards are frequently seen that have not been cultivated after irrigating. The quality of the fruit and the cultivated crop both show the lack of proper husbandry.

The soil of the Horse Heaven plateau is similar to that of the valley, both being lake deposit. The amount of rainfall is somewhat greater, yet not greatly in excess of that of the irrigated valleys. With proper cultivation a good yield of grain is generally raised on this plateau. With deep fall subsoiling, followed closely by early spring cultivation and very early deep seeding and a subsequent cultivation just before the grain joints, this country would be almost sure to yield well every year. Farmers on this elevated plateau, knowing that they must rely upon nature's precipitation to mature their crops, do their best to save all the water that falls. Their total rainfall is probably not equal to one single watering by the farmer in the valley. However, this piece of land is a constant object-lesson. It shows what may be done on a limited water supply when every drop of the supply is saved and used. In the semiarid belt of this State very little attention has been given to holding the moisture and to covering it with a fine tilth. When the conservation of moisture has been properly studied and made a part of practical agriculture the semiarid regions will largely increase their yield.

FALL AND WINTER IRRIGATION.

In the Moxee, where irrigation is relied upon and where a large ditch is now being constructed, a case is reported where a piece of ground was plowed in the fall and watered from an artesian well during the winter. It was seeded to wheat and received no water after seeding. This was done to utilize the winter's flow from the well, and not only produced a valuable crop, but also pointed to the value of fall plowing. The yield per acre of wheat hay was 2 tons. While it is not possible to irrigate from the ditches during winter, many of the advantages of winter irrigation could be secured by fall plowing and irrigating the latter part of October. It seems to be conceded that fall-irrigated crops come on earlier in the spring and make a better growth. Mr. C. P. Wilcox says: "My experience in this soil and climate teaches me that in most seasons four thorough irrigations are sufficient for fruit trees. A thorough irrigation in the fall, as late as can be done, say, in November, will save the first spring irrigation and be better, from the fact that the moisture will get evenly distributed through the soil where every root can feed on it." The necessity of such a method is not apparent so long as the large abundance of water now in use continues to be available, and it will likely continue so until much more of the fertile sagebrush land is placed under ditch. Even now it is likely that such a method would increase the yield of many crops. The setting-back effect of so many irrigations would at

least be partially eliminated, and the farmer would have further advantage of being able to irrigate when he has the most time to devote to doing it well. It is no small gain to the fertility of the soil at least that a man should have time to irrigate well and to save the leaching that comes from turning water loose to run over and off from a piece of land without sinking into it. It brings almost no fertilizer with it and leaves with a load of soluble salts, humus, and much light, fine vegetable matter that is lighter than water and easily floats off with it.

METHODS OF CULTIVATION.

HOPS.

Years of experience prove that the finest hops can be raised in the Yakima Valley. When prices are low yards may be neglected, but when properly cared for they always yield a bountiful crop. From 1,500 to 2,000 pounds per acre is an average crop. Some yards have been rented on the basis of the renter receiving 7 cents per pound for raising, picking, drying, baling, and delivering the hops at the warehouse. So all above 7 cents is net profit. The heat either kills the lice or holds them in check so that they do no harm. No spraying is done. If lice appear no attention is paid to them; the climate so successfully cares for them that no damage is done by their ravages.

Some yards are cultivated as often as eight times. One hop raiser said that cultivation was such a very important feature in hop raising that the yields would not be one-fourth of a crop without it, even though the amount of water was unlimited. The irrigator determines when the water is needed by examining the plant and the soil. If the weather is dry and hot, the last watering is as late as August. Some irrigators are very particular to water just at the blooming time. This practice secures a well-developed crop. The winter's precipitation is usually relied upon to supply the moisture until about the middle of May or the 1st of June, or until the crop has been plowed and strung. Some depend on cultivation to conserve the moisture, and do not water until in June. Hops are generally irrigated from three to four times during the season, depending very much upon the climatic conditions. They are usually cultivated after each watering and enough between wettings to keep down the weeds and to keep the surface in fine tilth. A prominent irrigator says hops or other cultivated crop will do no good unless cultivated after each watering, as the ground will bake in a few days. Another one says that it is claimed by some growers that frequent plowing and cultivation aids in preserving the moisture and in facilitating the growth of plant roots.

CORN.

Corn is raised in considerable quantities throughout the Yakima Valley. It is a good crop, yields well, and sells well, this being the only place in the State where it can be thoroughly matured.

Mr. Morris Sisk, having raised corn under the Sunnyside Canal for six years, advocates deep plowing and deep planting. He plows nearly 10 inches deep, plants from 6 to 8 inches deep and about 3 feet apart. When the corn is up from 6 to 8 inches high it is cultivated and afterwards irrigated for the first time about the last of June. Deep planting places the corn in moist soil, where it will quickly germinate and where the roots will be able to feed from deep sources. This obviates the necessity for early irrigation, which is said to stop the growth of the small plants and to make them turn yellow. Following the first irrigation the ground is given a deep cultivation. Mr. Sisk says he does not rely upon the looks of the plant to warn him when to irrigate, but upon the condition of the soil, the former being no true guide. On a hot day corn leaves will roll up when the soil is in prime condition. A cool evening and a little dew will make the plant look all right. Five out of six crops raised by Mr. Sisk have been as good as those which he formerly raised in Nebraska. The first one was not prime, due to shallow planting and early watering. The cold water of the snow-fed Yakima River put on tender plants in the early spring must of necessity check their growth. Deep plowing furnishes soil easily penetrated by the young roots. The deep planting puts young and tender roots in easy communication with a body of prepared earth and well away from the danger of surface evaporation. They will thrive while shallow-rooted plants will wither and die.

Unless the ground is very dry the practice seems to be not to water before planting, except, of course, on new land. All agree that it makes the ground cold and retards germination. Those who water before planting irrigate three times, once when corn is in tassel and once while the ear is forming. The last application should not be too late or it will be of little value. Any quantity of water after the ear is formed can not make up for previous neglect. Those who water twice use rather more and irrigate the first time when corn is about 2 feet high.

Mr. G. W. Mason says that the best results are secured by the use of barnyard manure and thorough cultivation. It seems to be well understood that cultivation, by forming a surface mulch, materially aids in holding the moisture while killing the weeds, and thus depriving them of their ability to evaporate it.

Mr. J. H. Moody says: "I begin cultivating as soon as corn is high enough, and after that I stir the ground about every ten days." In reply to the question "How do you know when to irrigate corn?" the answers vary considerably. Some depend entirely upon the looks of the plant, some rely entirely upon the condition of the ground, and some make up a judgment from both sources. From the replies, I should infer that some of the observers had carefully noted the soil conditions when the crop was doing its best, and so far as experience had taught them the required moisture content they had used that knowledge very intelligently in their irrigation practice.

So far no determinations have been made as to the amount of water required for a crop. However, one contributor recommends two waterings; first one, water only to run for twenty-four hours or just long enough to reach the lower end of the rows; at second watering to be allowed to run seventy-two hours.

ALFALFA.

Land should be carefully leveled before being seeded to alfalfa. It is always a good plan to plow after all grading has been completed and after the first watering. Such a plan will more than pay in the saving of future labor and trouble. When a field shows patches of bloom considerably earlier than the rest it is evidence that the ground was not well graded and that the water had not been well distributed, or else in leveling the plowed ground had nearly or quite all been removed from such places, leaving the subsoil hard. Under such conditions the percolation will be slower and the field will not mature evenly. Wheat is sometimes sown with alfalfa so that it may shade the ground and the young plants.

When land has just been seeded to alfalfa some farmers furrow about 6 inches deep, so as to be sure that no water comes to the surface. If it should flood the surface a crust would soon form, so the young plants could not get through. Sometimes the field is rolled. This packs the surface slightly and assists in holding the moisture near the surface and in contact with the young roots.

The practice in irrigating alfalfa is to give a light watering both before and after each cutting. All agree that this is a very important period, and if waterings are not timely and copious the following crop will be short.

Some clean out the furrows once or twice during the season and insist that the better distribution of the water more than pays in the increased crop for all the trouble. Some harrow or disk alfalfa in the spring and afterwards clean out the furrows. This breaks up the old crowns, mulches the surface, and assists the young shoots to start, besides preparing the ground to receive and hold moisture. If any places have become hard or baked they are broken up and a more even distribution of the water secured.

Alfalfa is grown much like clover. It is cut twice the first year, yielding 1½ to 3 tons, and about 5 tons the second year at three cuttings, after which it will yield 8 tons if well cared for, and is sometimes cut the fourth time. When not cut the fourth time the last growth makes fine fall pasture. With a liberal irrigation after the cutting of each crop from 1½ to 3 tons per acre can be harvested about every six weeks. One season with another, the average is about 8 tons per acre.

In 1897 there was exhibited at the Spokane fruit fair a 5-year old stalk of alfalfa whose root was 2 inches in diameter, with branches

which extended down 20 feet. The top was 8 feet and 3 inches high above the root. Generally the roots grow to be several inches in circumference and extend deep into the ground.

In reply to the question, "What does it cost you per ton to put alfalfa in the stack?" (this question is intended to cover every expense attached to raising, watering, and harvesting the crop) nearly all agree that where the land lays well, so it can be easily watered, $1.25 will cover all expenses. If the land is rough, 25 cents more should be added. The cost of seeding alfalfa is small, being about $5 per acre for seed and labor of sowing after the ground is prepared for the crop. The work of irrigating is also light, and the mat of roots prevents the soil from washing. The climate of the Sunnyside district is so dry that barns are not required for shelter, and the only expenses are those of irrigating, cutting, and stacking.

During the past season large quantities were sold in the stack at $4 per measured ton. A great many cattle and sheep that graze on the foothills during the summer are driven into the valley to be fed for market. This season 35,000 sheep and 6,000 cattle will be so fed, besides the stock of the farmers themselves. This always secures a good market and makes a large quantity of manure, which the farmers prize very highly.

The following is quoted from a published address of Mr. R. D. Young, of Sunnyside:

To show the productiveness of the Sunnyside country and the possibilities of dairying, I will give a few figures. During the season of 1899 and 1900 I fed 80 tons of hay; I milked during that time 6 cows, one of them 6 years old, one 3 years old, and four 2 years old each, all but one scrub or common cows.

Besides the 6 cows in milk, I fed 2 dry cows, 10 head of stock, 10 to 15 hogs, and 4 horses. The butter product sold from the 6 cows in milk realized $4 per ton for the 80 tons of hay fed to the stock mentioned, this after taking out the cost of the other feed.

Again, to show the possibilities of dairying, milking 7 cows:

One day's butter	$2.10
Three gallons milk sold	.60
One day's product	2.70
Cost of 56 pounds mill feed	.36
Net returns one day's product	2.34

Estimating the hay fed at 30 pounds to the cow would give 210 pounds fed. It will be seen that by dividing the hay fed, 210 pounds, into the net returns, $2.34, over 1 cent per pound is realized for the hay fed. Going still further with these figures, and taking the product of an acre of alfalfa, shown here we have $150 for an acre of hay. These figures are not imaginary. There is nothing estimated about them except the number of pounds of hay fed daily to each cow, and that, according to Professor Spillman, is too high. If too high, the net returns would increase in proportion.

ORCHARD.

Considering the fact that there are about 2,000 acres in orchard under the Sunnyside Canal, and that this acreage has constantly

increasing yearly additions, and that the trees are rapidly taking on size and spread of root, the application of water to orchard land, and the duty to be gotten out of it, are matters of vital importance.

As the lateral percolation in this soil is not great, a question has arisen as to whether furrows enough are provided to properly water a bearing orchard. A tree may live and do moderately well with its roots massed around some moist streak, but will it be as well nourished and yield as large returns in fruit as it would if its roots were more evenly distributed in a more evenly moistened soil? While it is agreed that water should not come in contact with the trees, yet it would seem that for a bearing orchard the water should be distributed (within the limits of convenience) as evenly as for any other crop. There does not appear to be much uniformity in the practice; some use more furrows for young orchards than for old, and others the reverse. Some use only one for bearing trees, while others use as many as five, 3 feet apart, between the rows of trees. Alfalfa fields prove conclusively that the furrows should be about 3 feet apart to properly wet the ground. The same rule will apply equally well to orchard, for the lateral percolation here will be no greater than in other cultivated crops. When only one or two furrows are used, the roots are crowded around these moist streaks, and draw their nourishment from only a small part of the soil that should be supplying them with food. They may do well while the land is new, but before many years it will become impoverished.

The better practice seems to be to furrow practically all of the ground between the rows. It would seem probable, at least, that such an even distribution of moisture would not only increase the crop but would add to the life of the soil or at least would keep it from being impoverished in streaks and would protect the trees from starvation while tons of fertile soil were around and below them, which, on account of being dry, could not be made to administer to their wants. All irrigation and all cultivation should look to making every foot of soil, to several feet in depth and for some distance about it, contribute to the growth and vigor of the tree and to the richness of the fruit.

All agree that in this climate, where the tree is liable to encounter killing frosts, cultivation and irrigation should stop early enough to allow the tree time to prepare to go into winter quarters. If no water is applied after the irrigation given to swell and mature the crop it is likely the tree will so far prepare for winter as to safely take water again late in October.

In reply to the question, "Do you think trees watered late in the fall are any more liable to winterkill?" Mr. F. E. Thompson says: "I do not; a thorough soaking in the fall prevents frost from going very deep into the soil." He says, further, "I have seen frost in semidry

soil 30 inches deep, and in ground that was soaked in the fall of the same year only 8 inches deep."

The practice of applying water to orchards varies widely. Some water early in April while others wait until well into May. The last watering is generally given the latter part of August. In a few instances where water is to be had it is again applied late in October or in November. Usually cultivation follows close after the watering. Some orchards are plowed late in the fall and again early in the spring. In such cases water is not turned on so early, the orchardist relying on the cultivation to conserve the moisture already in the ground. One irrigator says, "A dry dust mulch holds the water more than as long again."

In some young orchards water is run through old ditches year after year with no cultivation following, some growers insisting that young trees will do fairly well under such conditions. However, the writer has never seen any so treated that could be considered prime. Fortunately, if water is run through old ditches, trees and other plants may get moisture enough to keep them alive, but there will not be enough moist earth to feed a large crop. The better practice is based upon abundant cultivation throughout the growing season.

In young orchards vegetables and root crops are frequently raised between the rows. There is some doubt about the gain, but, on the whole, if the crops are well watered and cultivated there is an immediate material gain until the tree is large enough to shade the ground and until it begins to bear. The plan surely secures a better distribution of roots and thus supplies the tree with a larger food area, which will add materially to its ability to produce abundantly of perfect fruit. The plan of raising alfalfa or clover in bearing orchards is generally condemned. In some instances a poorly cultivated, weedy crop of corn is seen among fruit trees. In such cases there is neither a crop of corn nor of fruit. These cases are rare and only go to show that occasionally there is yet to be found a man who has eyes to see with and yet can not see the almost perfectly irrigated farms immediately about him.

Just before fruit ripens and just as it begins to swell it is given a final watering. This insures large, well-formed fruit.

On November 28, 1896, a hard freeze killed a good many trees. Previous to that time orchards had been watered until late in October. On account of the damage, which was charged up to late watering and unmatured timber, the tendency has been to turn the water off earlier in the fall. Some report last irrigation the latter part of August. Others water in September, and even as late as the first of October. Very late fall irrigation, after the trees have shed their foliage, would seem to be warranted. It would protect the trees from winter evaporation and aid in the deeper penetration of moisture and

roots. Further, it has been demonstrated that when trees are well supplied with moisture they are less liable to winterkill. Not only this, but should the winter precipitation be sufficient to further saturate the ground it will aid in delaying the budding season. In reply to the question, "Would late winter or early spring irrigation check the development of buds and so protect against late frosts?" there was a diversity of opinion. Some had given the matter no attention; others reported that along laterals carrying water the fruit was better and that there was more of it in seasons when frost had damaged the remainder of the crop. One orchard supplied with an artesian well had water running near some apricot trees all winter and spring. The budding was not only delayed, but the trees so watered matured their crop earlier. In another instance, a gentleman who was gathering fruit for an exhibition noticed that in a little apple orchard the first row of trees next to the lateral bore fine fruit, while in the remainder of the orchard the fruit was killed by frost. Another orchardist says: "I have noticed that plenty of cold water applied early retards early development." One says: "Late spring frosts are most damaging to trees standing in comparatively dry soil."

MONTANA.

IRRIGATION INVESTIGATIONS IN MONTANA, 1900.

By Samuel Fortier, C. E.,

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THE PROPER QUANTITY OF WATER TO APPLY.

The investigations that were carried on during the summer of 1899 were planned with the view to ascertaining the actual quantities of water used by irrigators, the percentage of loss in their canals, the method of distribution, and the principal conditions which affect the duty of water. At the beginning of the season just closed similar lines of work were taken up, the only difference from the preceding year being in more extended operations throughout different parts of the State. In addition to these investigations it was thought desirable to institute a second series of experiments at the Montana Experiment Station farm, for the purpose of determining the proper amounts of water to apply to growing crops and the proper time to irrigate. It is intended that this series shall extend through a period of at least five years, during which time the staple crops of Montana can be experimented upon with the object of finding out how much water is necessary to produce the most valuable yields and the right time to apply it. It will be noticed that this series is supplementary to investigations carried on in former years. It was necessary first to ascertain what use was made of irrigating water, and with this information as a basis to conduct experiments along more scientific lines in trying to demonstrate to the irrigator the mistakes he was making in using either too little or too much water, or in irrigating at the wrong time.

Last spring a distributing flume was built in such a manner that it could be readily taken apart and placed in any location desired. The sides and bottom consisted of 1½-inch planks, held in place by yokes placed 4 feet apart. This flume was connected with a weir box at its upper end, and in the weir box there was an adjustable wasteway by which the water admitted into the flume could be regulated (Pl. XVII). By this device the water could not only be measured as it passed into the distributing flume, but diminished or increased to any desired amount up to the total flow of the lateral. Along the right side of this flume plats to the number of sixteen were laid off.

Each plat was 50 feet wide and 100 feet long and was separated from bordering plats by strips of bare ground 15 feet wide. The object of having strips of bare ground between the plats is to prevent the passage of water, either by seepage or otherwise, from one plat to another. On May 21, 1900, all the plats were seeded to oats at the rate of 2 bushels of seed per acre. Nine days later the percentage by weight of moisture contained in the soil of each plat was determined by Mr. Edmund Burk, under the supervision of the chemist of the station, Dr. Traphagen. A sample of soil, extending from the surface to a depth of 2 feet, was obtained from the center of each plat by means of a 1.5-inch auger. This cylinder of soil, 1½ inches in diameter and 24 inches in length, was placed in a glass jar and the lid screwed tightly down to prevent evaporation. The following are the results found after evaporating the entire moisture content and comparing the loss in weight thus effected with the original weight of the sample:

Sample from plat—	Moisture per cent.
No. 1	18.30
No. 2	19.97
No. 3	17.74
No. 4	18.05
No. 5	18.94
No. 6	18.08
No. 7	17.29
No. 8	18.65
No. 9	20.26
No. 10	19.03
No. 11	20.95
No. 12	20.46
No. 13	18.08
No. 14	17.81
No. 15	19.30
No. 16	20.30

These results show that the soil of the plats to a depth of 2 feet was composed of nearly one-fifth by weight of water and that the amount of moisture in each was practically equal, the driest plat containing 17.29 per cent and the wettest 20.95 per cent.

On June 25 the first irrigation was begun. A measured quantity of water was allowed to flow through the flume to each plat, which was irrigated separately. Small galvanized iron slides, moving vertically in grooves and placed over 1.75-inch openings, controlled the flow from the distributing flume to each plat. The water through these openings (Pl. XVII, fig. 1), which were spaced 4 feet apart, was allowed to flow onto the plat until the earth became so moist that part of the water began to escape. It was found that a depth of 4 inches over the surface was as much as could be applied at any one time without waste. Had the plats been arranged in terraces, with

FIG. 1.—DISTRIBUTING FLUME, MONTANA EXPERIMENT STATION.

FIG. 2.—MEASURING BOX, WATERWAY AND DISTRIBUTING FLUME, MONTANA EXPERIMENT STATION.

a low embankment around each, it would have been possible to have applied a larger quantity of water at one time and thus reduce the number of irrigations. This mode of irrigating is not, however, practiced in Montana, and it was deemed important that the experiments conform as closely as practicable to the methods commonly employed. In the case of a large field, it is possible to allow the water to flow slowly over the surface until the ground is wet for a foot or more in depth. With the small plats, and using the flooding method, the water could not flow long over the surface without waste, and a less quantity of water had to be used at more frequent intervals. The quantities of water applied to each plat, when measured in depth over the surface, as well as the corresponding dates, are given in the accompanying table.

Table showing dates of irrigations and depths of water applied.

Number of plat.	Dates of irrigation.	Depth applied.	Remarks.
		Inches.	
1	(1)		Received some moisture from adjacent ditch and a leaky flume.
2	June 25	2	Oat crop from 6 to 9 inches high.
3	June 25	4	Same as on plat No. 2.
	July 16	4	Height of grain, 23 inches; 3 per cent headed out.
4	June 25	5	Same as on plat No. 2.
	July 16	4	4 per cent headed out.
5	June 26	4	Same as on plat No. 2.
	July 16	4	3 per cent headed out.
	July 26	4	Height of grain, 37 inches.
6	June 26	4	Same as on plat No. 2.
	July 6	4	Grain 16¼ inches high.
	July 16	4	Grain 23 inches high.
	July 27	4	Grain 41 inches high.
7	June 26	4	Same as on plat No. 2.
	July 6	4	
	July 17	4	2 per cent headed out.
	July 27	4	
	Aug. 6	4	Grain 55 inches high.
8	June 26	4	Same as on plat No 2.
	July 6	4	Same as on plat No 6.
	July 16	4	3 per cent headed out.
	July 27	4	
	Aug. 6	4	
	Aug. 15	4	

[1] Not irrigated.

In comparing the depth of water applied to each plat as expressed in inches with the yield of grain a glance at the table given below will show the close relation between the amount of water and the yield. These results, however, may not represent the average of a number of years. The past season was extremely dry, and the soil-moisture tests showed that the greater part of each watering was soon evaporated. In view of these exceptional conditions no attempt will be made here to draw conclusions from the results obtained from one season's operations.

The following table gives the depths of water applied, the yields per plat in grain and straw and the corresponding yields per acre, allowing 34 pounds of oats per bushel.

Depth of water applied, the yield per plat, and the corresponding yields per acre.

Number of plat.	Depth of water.	Grain per plat.	Straw per plat.	Total.	Yield per acre. Grain.	Yield per acre. Straw.
	Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Bushels.*	*Pounds.*
1	0	180	190	370	46.122	1,655.28
2	2	241	284	525	61.729	2,345.408
3	8	266	324	590	68.158	2,822.688
4	9	287	343	630	73.539	2,968.216
5	12	292	353	645	74.825	3,075.336
6	16	305	390	695	78.151	3,397.68
7	20	303	377	680	77.639	3,284.424
8	24	326	369	695	83.532	3,214.728

DUTY OF WATER IN GALLATIN VALLEY.

EXPERIMENT NO. 1.

The duty of water varies greatly on the same field in different seasons and for different crops. On a field of clover belonging to the Hon. James E. Martin, situated in the southeastern part of Gallatin Valley, the quantity of water applied during the past season was nearly 2 feet over the surface in two irrigations, while the same field when seeded to barley received in 1899 a trifle less than 1 foot in one irrigation.

The field slopes from the south to the north at the rate of about 80 feet to the mile and also to the east to a less extent. The field laterals were parallel and ran diagonally through the field on a grade of about 15 inches to the rod. The distance between the laterals ranged from 56 to 93 feet and averaged 69 feet. The soil consists of a clay loam with a porus stratum of gravel wash beneath. This field was summer-fallowed in 1897, seeded to barley and oats in 1898, the yield being 73 bushels per acre of barley and 50 bushels of oats; was seeded down to red clover with barley as nurse crop in 1899, and produced two crops of clover during the season just closed.

The following table gives the results of the measurements made:

Duty of water on clover as shown by experiment No. 1.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 14-26	July 28-Aug. 17	
Duration of irrigation .... hours	286	478	764
Area irrigated .... acres	66.39	66.39	66.39
Water used .... acre-feet	87.32	44.46	131.78
Depth of water used in irrigation .... feet	1.31	.67	1.98
Rainfall, May 1 to September 10 .... foot			.44
Total depth of water received during growth, feet			2.42
Number of irrigators	2	2	
Average head of water used, cubic feet per second	3.955	1.13	
Average distance between field laterals .... feet			69

EXPERIMENT NO. 2.

This test was made on a field of barley, 4.14 acres in extent, located near the southwest corner of the experiment station farm. This field has been cropped continuously since 1893. It produced potatoes in 1894, barley in 1895, oats in 1896, peas in 1897, barley in 1898, peas in 1899, and barley in 1900. The barley was sown April 20, 1900, irrigated for the first time June 12 and 13, irrigated a second time June 29 to July 1, and harvested August 17. The yield from the field was 200.8 bushels, or 48.5 bushels per acre.

Duty of water on barley as shown by experiment No. 2.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 12-13	June 29 to July 1	......
Duration of irrigation .... hours	25.5	38	63.5
Area irrigated .... acres	4.14	4.14	4.14
Water used .... acre-feet	3.30	2.91	6.21
Depth of water used in irrigation .... feet	.797	.703	1.50
Rainfall during growth .... foot	....	....	.28
Total depth of water received during growth, feet	....	....	1.78
Number of irrigators	2	2	....
Average head of water used, cubic feet per second	1.567	.9255	....
Average distance between field laterals .... feet	....	....	85

EXPERIMENT NO. 3.

A test was made in 1899 on a field of oats belonging to Mr. J. L. Patterson, county commissioner of Gallatin County. Last spring Mr. Patterson again seeded the same field to oats, and the quantity of water used was measured over the same weirs that were built the year previous.

The results as given in the accompanying table indicate that 15.58 acre-feet of water was applied at the first irrigation and 5.44 acre-feet at the second. The latter, however, was incomplete in that only about two-fifths of the area of the field was irrigated.

Duty of water on oats as shown by experiment No. 3.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 18-21	July 23-29	....
Duration of irrigation .... hours	80.25	147	227.25
Area irrigated .... acres	25.09	25.09	25.09
Water used .... acre-feet	15.58	5.44	21.02
Depth of water used in irrigation .... foot	.621	.22	.84
Rainfall during growth .... do	....	....	.39
Total depth of water received during growth .... feet	....	....	1.23
Number of irrigators	1	1	....
Average head of water used .... cubic feet per second	2.35	.45	....
Average distance between field laterals .... feet	....	....	85

EXPERIMENT NO. 4.

For the past four years a regular rotation of crops has been conducted on a tract of land 1,227 feet long and 218 feet wide on the experiment station farm. This tract is divided lengthwise into six equal plats of 1 acre each, with strips of bare ground 3 feet wide between the plats. The order of the rotation is barley, clover, wheat, peas, oats, and sugar beets.

During the season just closed three separate tests were made on these acre plats. The clover and wheat were irrigated together, as were also the peas and oats, and the remaining test was made on the acre of barley. The soil is more than of average fertility, consisting of vegetable loam, clay loam, and clay marl, underlaid about 6 feet below the surface with an unknown depth of gravel and cobble rock.

The wheat was seeded May 4, cut August 28, and yielded 38.33 bushels to the acre plat. The clover was seeded May 7, without a nurse crop, cut August 17, and yielded 3,170 pounds of cured hay. The following table shows the duty of water:

Duty of water on 1 acre of wheat and 1 acre of clover as shown by experiment No. 4.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 18	July 11-12	
Duration of irrigation ... hours	6	7.58	13.58
Area irrigated ... acres	2	2	2
Water used ... acre-feet	.66	.88	1.54
Depth of water used in irrigation ... foot	.33	.44	.77
Rainfall, May 5 to August 20 ... do			.30
Total depth of water received during growth ... feet			1.07
Number of irrigators	2	2	
Average head of water used ... cubic feet per second	1.34	1.40	
Average distance between field laterals ... feet			36

EXPERIMENT NO. 5.

This experiment was made on the peas and oats of the rotation plats. The peas were seeded May 5, cut September 25, and yielded 1,330 pounds. The oats were seeded May 4, cut August 13, and yielded 75.58 bushels per acre plat. The following table contains the data pertaining to this experiment:

Duty of water on 1 acre of oats and 1 acre of peas as shown by experiment No. 5.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 18	July 11	
Duration of irrigation ... hours	4.83	5	9.83
Area irrigated ... acres	2	2	2
Water used ... acre-feet	.55	.57	1.12
Depth of water used in irrigation ... foot	.28	.29	.57
Rainfall, May 4 to August 25 ... do			.39
Total depth of water received during growth ... feet			.96
Number of irrigators	2	2	
Average head of water used ... cubic feet per second	1.38	1.37	
Average distance between field laterals ... feet			36

EXPERIMENT NO. 6.

This experiment was made on the barley of the rotation plats. This acre was seeded to barley May 5, cut August 25, and yielded 87.29 bushels.

Duty of water on barley as shown by experiment No. 6.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 19	July 12	
Duration of irrigation ... hours	6.71	3.92	10.63
Area irrigated ... acres	1	1	1
Water used ... acre-feet	.66	.51	1.17
Depth of water used in irrigation ... foot	.66	.51	1.17
Rainfall May 5 to August 25 ... do			.28
Total depth of water received during growth ... feet			1.45
Number of irrigators	2	2	
Average head of water used ... cubic feet per second	1.18	1.58	
Average distance between field laterals ... feet			36

EXPERIMENT NO. 7.

The quantity of water used on an oat field located at the southwest corner of the experiment station farm was also determined. The field slopes to the north at the rate of about 90 feet to the mile and also to the east to a like degree.

The oats were sowed May 2, irrigated about the middle of June and also at the end of the first week in July, and harvested August 28. The total yield on the field of 8.51 acres was 635.5 bushels of 34 pounds, or at the rate of 74.67 bushels per acre, and the selling price at this writing (November 10) is 87 cents per hundred pounds. This field has been cropped for eight years. It was seeded to oats in 1893, peas in 1894, and barley in 1895. It was in clover for three years—from 1896 to 1898, inclusive. Last year it was seeded to wheat and barley; the wheat yielded on an average 57.89 bushels per acre and the barley 45 bushels. The results of two irrigations are given in the following table:

Duty of water on oats as shown by experiment No. 7.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 15–17	July 6–7	
Duration of irrigation ... hours	41.5	29.33	70.83
Area irrigated ... acres	8.51	8.51	8.51
Water used ... acre-feet	5.98	4.81	10.79
Depth of water used in irrigation ... foot	.70	.57	1.27
Rainfall, May 2 to August 28 ... do			.40
Total depth of water received during growth ... feet			1.67
Number of irrigators	2	2	
Average head of water used ... cubic feet per second	1.74	1.98	
Average distance between field laterals ... feet			90

EXPERIMENT NO. 8.

This test was made on a field of barley containing 4.52 acres located on the experiment station farm. The field prior to 1897 produced little but weeds. It was seeded to barley in that year and to peas in 1898. Potatoes were planted in 1899, and the crop of barley grown the past season was sowed April 21, cut August 16, and produced 14,880 pounds, or at the rate of 68.58 bushels per acre. The grain was sold for 87 cents per hundred pounds.

Duty of water on barley as shown by experiment No. 8.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 13-14	July 1-2	
Duration of irrigation ....hours	24.5	30	54.5
Area irrigated ....acres	4.52	4.52	4.52
Water used ....acre-feet	4.42	4.43	8.85
Depth of water used in irrigation ....feet	.98	.98	1.96
Rainfall during growth ....foot			.42
Total depth of water received during growth ....feet			2.38
Number of irrigators	2	2	
Average head of water used ....cubic feet per second	2.19	1.79	
Average distance between field laterals ....feet			75

EXPERIMENT NO. 9.

This experiment was made on a field of clover containing 7.26 acres and situated on the south side of the experiment station farm. The field has been cropped continuously since the establishment of the farm in 1893. Last year it was seeded to oats and red clover, and it produced during the past season two heavy crops of clover hay. The first crop was cut and stacked from July 1 to 15, and yielded 19 tons and 15 pounds; the second crop was cut and stacked from September 1 to 15, and yielded 17 tons and 930 pounds, or a total of over 5 tons per acre. The price of clover hay in the stack is from $5 to $6 per ton. The quantity of water applied at four irrigations was 2.7 feet. Compared with the results obtained from the other fields, this would seem to be an excessive amount. There was, however, but a small percentage wasted, and it is questionable if a less amount of water would have produced as great a yield.

Duty of water on clover as shown by experiment No. 9.

	First irrigation.	Second irrigation.	Third irrigation.	Fourth irrigation.	Total.
Date of irrigation	June 4-5	July 3-5	July 19-21	Aug. 1-4	
Duration of irrigation ....hours	26	50.25	27.5	67	170.75
Area irrigated ....acres	7.26	7.26	7.26	7.26	7.26
Water used ....acre-feet	4.21	6.61	4.49	4.31	19.62
Depth of water used in irrigation ..feet	.58	.91	.62	.59	2.70
Rainfall, May 1 to Sept. 10 ....foot					.44
Total depth of water received during growth ....feet					3.14
Number of irrigators	2	2	2	2	
Average head of water used, cubic feet per second	1.96	1.59	1.97	.78	
Average distance between field laterals ....feet					76

EXPERIMENT NO. 10.

During the past season a test was again made on the clover field situated in the southeast corner of the experiment station farm, and described in the report for 1899[1] as experiment No. 1. This season the field was increased by the addition of another small clover field. The quantities of water applied at each irrigation were only slightly in excess of those of last year, but, owing to the long, dry season, the date of the first watering was ten days earlier, in consequence of which three irrigations were necessary, and the total depth of water applied was 1.78 feet, an increase of 0.77 foot over that of last year.

The results of the experiment are given in the following table:

Duty of water on clover as shown by experiment No. 10.

	First irrigation.	Second irrigation.	Third irrigation.	Total.
Date of irrigation	June 5-7, 8-11	July 13-16, 20-24.	July 26-28, Aug. 8-14.	....
Duration of irrigation .... hours	116.42	152.5	189.83	458.75
Area irrigated .... acres	35.9	35.9	35.9	35.9
Water used .... acre-feet	21.85	25.50	16.65	64
Depth of water used in irrigation .... feet	.61	.71	.46	1.78
Rainfall, May 1 to Sept. 10 .... foot	....	....	....	.44
Total depth of water received during growth .... feet	....	....	....	2.22
Number of irrigators	2	2	2	....
Average head of water used, cubic feet per second	2.27	2.02	1.06	....
Average distance between field laterals . feet	....	....	....	80

DUTY OF WATER UNDER MIDDLE CREEK CANAL.

The area irrigated under the Middle Creek Canal during the past season was 3,853 acres. The daily flow of the canal was obtained by means of the same rating flume and automatic register that were used during the preceding year, and the results are given in the following table:

Daily discharge of Middle Creek Ditch, June 4 to September 16, 1900.

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	106.65	31.08	25.25
2	....	95.96	40.96	25.25
3	....	97.45	33.75	24.36
4	32.47	93.43	32.97	27.94
5	137.86	89.97	41.09	26.93
6	145.10	79.84	51.43	23.74
7	154.63	71.63	50.07	22.96
8	151.98	84.71	43.05	23.17
9	147.44	68.44	40.87	23.74
10	137.41	64.28	42.83	24.77
11	133.18	58.54	45.00	39.14
12	147.05	75.30	44.88	25.53
13	164.84	54.91	26.17	24.34
14	164.95	49.24	40.52	27.14
15	175.16	45.66	40.52	25.55
16	181.36	41.58	41.74	30.33
17	176.76	45.76	37.03	....
18	152.70	44.88	37.65	....
19	149.25	41.05	38.29	....
20	137.29	45.80	29.66	....
21	143.52	44.97	29.34	....

[1] U.S. Dept. Agr., Office of Experiment Stations Bul. 86.

Daily discharge of Middle Creek Ditch, June 4 to September 16, 1900—Continued.

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
22	162.90	43.96	28.47	
23	170.30	44.75	28.68	
24	163.42	46.37	26.70	
25	159.55	45.20	25.14	
26	165.28	62.91	25.25	
27	143.50	59.23	25.46	
28	106.33	59.12	25.23	
29	106.31	59.25	25.37	
30	106.33	51.22	25.25	
31		40.29	25.25	
Total	3,916.87	1,912.35	1,074.70	420.14

Duty of water under Middle Creek Canal, 1900.

Area irrigated	acres	3,853.00
Water used	acre-feet	7,324.06
Depth of water used in irrigation	feet	1.90
Depth of rainfall during season	foot	.45
Total depth of water received by land	feet	2.35

In 1899 the average depth of water applied to the land under this canal was 2.11 feet. There was a more abundant supply in Middle Creek and the season was not so dry as that just closed. This difference between the available water supply and the rainfall of the two seasons accounts for the difference in the duty of water.

DUTY OF WATER IN YELLOWSTONE COUNTY.

This county extends from the central part of the State eastward a distance of about 90 miles, and comprises an area of 4,500 square miles. The Yellowstone River forms its southern boundary.

This part of the State has an abundant supply of water. The flow of the Yellowstone at Livingston, Mont., varies from 200,000 to 600,000 Montana statutory inches, or 50,000 to 150,000 cubic feet per second, during the irrigation period. In addition to the main river, there are the large tributaries, Boulder, Stillwater, and Clarkes Fork, besides about thirty small creeks that provide an irrigating supply for the counties of Sweetgrass, Carbon, and Yellowstone.

Irrigation is still in the early stages of development in this county. Little was accomplished in reclaiming its large tracts of tillable land prior to 1885, but during the past ten years the growth along agricultural lines has been remarkable. The principal irrigation ditches in operation at the present time are the following:

(1) The Yellowstone Ditch, which diverts water from the Yellowstone River at the Rapids above Park City and extends to Valley Creek.

(2) The Big Ditch, which diverts water from the same river just below the rapids and extends toward the city of Billings, a distance of 39 miles.

(3) The Italian Ditch, which heads above Park City and extends to Laurel, a distance of 15 miles.

(4) The Old Mill Ditch, which also heads above Park City and terminates opposite the town of Laurel, its total length being about 15 miles.

(5) The Canyon Creek Ditch has its source near Laurel, and waters a portion of the country between Laurel and Billings.

(6) The Suburban Ditch heads at Canyon Creek and extends to Billings, a distance of 5 miles.

Investigations were begun in May, 1900, in Yellowstone County, for the purpose of determining the quantities of water used by the irrigators and the percentage of loss in conveyance. For the results of the experiments on the loss due to seepage and evaporation the reader is referred to the information given under that heading.

In order to ascertain the quantities of water applied to the various crops in this section of the State, measuring stations were established at three different points on the Big Ditch, and a daily record kept of the flow at each from May 25 to September 27. The first of these stations was at Tilden's ranch, about 5 miles below the headgates on Yellowstone River; the second at Park City; and the third at the Hesper farm, located 11 and 27 miles, respectively, below the headgates.

In the accompanying table is given the daily flow at the Tilden rating station from May 25 to September 27, inclusive:

Daily discharge of Big Ditch at Tilden's ranch, 5 miles below headgates, May 25 to September 27, 1900.

Day.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	386.35	470.04	375.83	282.64
2	....	386.35	470.04	365.93	282.64
3	....	427.42	470.04	365.93	282.64
4	....	470.04	470.04	365.93	282.64
5	....	511.71	470.04	365.93	282.64
6	....	511.71	470.04	225.13	262.79
7	....	511.71	470.04	345.11	262.79
8	....	511.71	470.04	345.11	262.79
9	....	511.71	476.04	292.55	262.79
10	....	511.71	470.04	292.55	292.55
11	....	511.71	470.04	345.11	282.64
12	....	511.71	449.24	322.50	282.64
13	....	511.71	470.04	292.55	282.64
14	....	511.71	449.24	292.55	262.79
15	....	511.71	449.24	292.55	262.79
16	....	511.71	449.24	292.55	262.79
17	....	511.71	406.60	322.50	242.97
18	....	511.71	406.60	322.50	242.97
19	....	511.71	386.75	345.11	242.97
20	....	511.71	406.60	345.11	242.97
21	....	511.71	386.75	322.50	225.12
22	....	470.04	386.75	322.50	225.12
23	....	470.04	386.75	322.50	207.28
24	....	470.04	386.75	322.50	207.28
25	262.79	470.04	386.75	322.50	207.28
26	271.73	480.95	386.75	322.50	207.28
27	321.72	480.95	365.93	322.50	207.28
28	302.46	491.86	406.60	322.50	....
29	313.38	470.04	406.60	322.50	....
30	334.20	470.04	386.75	292.55	....
31	386.35	....	386.75	282.64	....
Total	2,192.63	14,643.23	13,317.12	9,900.72	6,851.72

As regards the areas over which this large volume of water was applied, the funds available for these investigations would not permit of actual survey, but the writer received from Mr. I. D. O'Donnell, the president and general manager of the Big Ditch Company, an estimate of the areas irrigated during the past season in the various crops, the average yields, and the probable values. The following is Mr. O'Donnell's estimate:

Crops under Big Ditch, 1900.

Crops.	Number of acres.	Yield.	Value.
		Tons.	
Alfalfa	10,000	50,000	$250,000
Timothy and blue joint	4,000	6,000	60,000
		Bushels.	
Oats	4,000	200,000	67,000
Wheat	1,500	37,500	37,500
Sundries	1,500	....	75,000
Pasture	4,000	....	3,000
Alkali	1,000	....	....
Total	25,000	....	492,500

Assuming the area to be 25,000 acres, and the volume of water conveyed 46,995.42 acre-feet, the duty of water under this canal, irrespective of loss in conveyance, would be equivalent to that amount which would cover each acre watered to a depth of 1.88 feet, or less than one-third of a miner's inch per acre for the season. The table of discharges shows, however, that 10,320 miner's inches were applied for over two weeks in June, and this maximum flow would be equivalent to a trifle more than two-fifths of a miner's inch per acre during the busy season.

These figures represent what may be termed the gross duty of water, and the net duty would be found after deducting all the losses due to seepage and evaporation in the canal. The loss in 22 miles of this canal last July, as stated under the head of "Loss from seepage and evaporation," was a trifle more than 25 per cent of the total flow, and the quantity of water entering the farmer's headgates would be only three-fourths of the total available supply at Tilden's rating station.

The following table sums up the data for this canal:

Duty of water under Big Ditch, 1900.

Area irrigated .... acres..	25,000
Water used .... acre-feet..	46,995.42
Depth of water used in irrigation .... feet	1.88
Loss from seepage and evaporation (25 per cent) .... do...	.47
Depth of water received from irrigation .... feet..	1.41
Depth of rainfall during season .... foot	[1].45
Total depth of water received by land .... feet..	1.86

[1] Bozeman records.

In addition to the general test which was made on the largest canal in Yellowstone County, one of the largest in the State, the quantity of water used on a large field of alfalfa was also ascertained. The alfalfa field, composed of a clay loam, formed part of the Hesper farm, the property of Mr. I. D. O'Donnell. A trapezoidal weir, built under the supervision of the writer at the expense of the owner of the farm, was inserted at the highest point of the field, and a record kept of the flow over the weir during the period of ten days required to irrigate this crop. The field produced three crops of alfalfa, which aggregated 276 tons of 422 cubic feet per ton, measured in the stacks September 24, 1900, and at that date the fourth crop was 8 inches high.

Duty of water on alfalfa in Yellowstone County, 1900.

Date of irrigation		July 17-27
Duration of irrigation	hours	240
Area irrigated	acres	58.4
Water used	acre-feet	69.5
Depth of water used in irrigation	feet	1.30
Rainfall, May 1 to September 15[1]	feet	.45
Total depth of water received during growth	do	1.75
Average head of water used	cubic feet per second	3.52

INVESTIGATIONS IN THE BITTER ROOT VALLEY.

The Bitter Root Valley, from an agricultural point of view, is one of the most important in Montana, and one of the most beautiful in the Rocky Mountain region. Irrigation investigations were begun in May, 1900, and continued throughout the season. The cost of traveling between the Yellowstone, Gallatin, and Bitter Root valleys took a part of our small appropriation, and the work of the past season in western Montana would have been limited in extent had it not been for the generous aid extended to the writer by the officers of the Bitter Root stock farm. The materials and labor necessary to construct three large trapezoidal weirs, one rating flume, and several rating stations were obtained from this source. A rating station was established near the head of each of the large canals taken out of the Bitter Root River and Skalkaho and Gird creeks soon after the beginning of the irrigation season, and daily records of the amount of water flowing in each were kept by Mr. Kippen, in charge of irrigation. If these stations and records can be maintained for another season, it will be possible to ascertain the duty of water during two seasons for an irrigated area of about 15,000 acres.

The upper part of the valley consists of bottom lands, lower bench lands, and upper bench lands. The older ditches, such as the Surprise and Republican, water the river bottoms; the intermediate

[1] Bozeman records.

ditches, such as the Ward and Hedge, water the lower bench; while of late years long high-line ditches, such as the Upper Gird, have been constructed to supply water to the upper benches. These water courses, located one above another, on the sloping bench of the Bitter Root River, complicate the problem of seepage waters. Already some of the farms, and especially the orchard tracts, are depreciating in value, owing to an excess of seepage water from the higher benches. This injury to low-lying lands will continue to increase if radical measures are not taken either to lessen the waste or to construct intercepting drains. Before attempting any improvements of this character it is advisable to ascertain the loss from seepage in each canal.

In another part of this report will be found the results of seepage measurements on the Republican Canal. As this canal skirts the river hroughout the greater part of its course, the seepage water escaping therefrom soon reaches the river channel, and can therefore do little damage, although it is essential to know the quantity wasted in order to divide the remainder equitably. It is to be hoped that similar measurements may soon be made on the high-line canals in order that the loss in each may be known and measures taken to prevent serious damage to adjacent lands.

DUTY OF WATER.

Experiment No. 1.—The first experiment on the duty of water in the Bitter Root Valley was made on a 40-acre tract of 5-year-old orchard trees located on the Lower Ward ranch of the Bitter Root stock farm. The soil to a depth of 6 inches is a light vegetable loam, and beneath this top layer to a depth of 4 feet are to be found gravel and cobble rock. The water was measured over a trapezoidal weir box 12 feet long and a weir notch 3 feet long. The rainfall during the growing season was obtained from Mr. G. W. Dougherty, weather observer at Corvallis, a few miles distant. This rainfall, together with the water applied, in four irrigations would have covered the orchard, provided there was no waste, to a depth of a trifle more than 18 inches. The results of this experiment are given in the following table:

Duty of water on orchard, Bitter Root stock farm.

	First irrigation.	Second irrigation.	Third irrigation.	Fourth irrigation.	Total.
Date of irrigation	[1] Apr. 28–30	June 7–13	July 9–14	Aug. 12–14	......
Duration of irrigation .... hours	58	153.5	125.5	57	394
Area irrigated .... acres	40	40	40	40	40
Water used .... acre-feet	12.25	17.57	28.03	1.36	59.21
Depth of water used in irrigation ... feet	.31	.44	.7	.03	1.48
Rainfall, May 1 to Aug. 14 .... foot	....	....	....	....	.13
Total water received during growth, feet	....	....	....	....	1.61
Average head of water used, cubic feet per second	2.56	1.39	2.7	2.89	....

[1] Approximate.

Experiment No. 2.—The second experiment was made on a large field of oats containing 161.7 acres, located on the Prendergast ranch of the Bitter Root stock farm. The field slopes at the rate of nearly 45 feet to the mile, and the soil consists of about a foot of black vegetable loam overlying an unknown depth of coarse gravel. This field was seeded April 15 and cut August 10, and the yield was 5,296 bushels of 35 pounds to the bushel. The accompanying table shows that the total depth of water received was 1.28 feet from irrigation and 0.13 foot from rain, or 1.41 feet in all, which equals about 17 inches.

Duty of water on oats, Bitter Root stock farm.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	May 22–June 11	July 21–30	... .
Duration of irrigation ... hours	490.5	226.5	717
Area irrigated ... acres	161.7	161.7	161.7
Water used ... acre-feet	125.75	81.23	206.98
Depth of water used in irrigation ... feet	.78	.5	1.28
Rainfall, Apr. 15 to Aug. 10 ... foot	....	....	.13
Total depth of water received during growth ... feet	....	....	1.41
Average head of water used ... cubic feet per second	3.1	4.35	....
Average distance between field laterals ... feet	....	....	175

Experiment No. 3.—This experiment was made on a high gravelly bench traversed by numerous ravines, and is a typical example of the enormous quantities of water that may be applied to certain bench lands by the ordinary methods of irrigating as practiced in the mountain States. On this particular field of oats, containing 102.2 acres, located on the Gilchrist ranch of the Bitter Root stock farm, and supplied with water from the Skalkaho Ditch, the farm laterals were from 150 to 200 feet apart, and the irrigators were on duty nine hours out of every twenty-four. The yield was 3,478 bushels of oats. The data pertaining to this experiment are given in the following table:

Duty of water on oats, Bitter Root stock farm.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	May 23–June 19	July 19–Aug. 8	....
Duration of irrigation ... hours	656.08	418.17	1,074.25
Area irrigated ... acres	102.2	102.2	102.2
Water used ... acre-feet	347.46	265.87	613.33
Depth of water used in irrigation ... feet	3.4	2.6	6
Rainfall, Apr. 15 to Aug. 10 ... foot	....	....	.13
Total depth of water received during growth ... feet	....	....	6.13
Number of irrigators	....	....	2
Average head of water used ... cubic feet per second	6.41	7.69	....
Average distance between field laterals ... feet	....	....	175

SEEPAGE IN ITS RELATION TO THE DUTY OF WATER.

SEEPAGE DEFINED.

The term seepage has a somewhat wide meaning in the irrigated sections of the West. In its broader sense it includes any water which percolates the soil. In its narrower sense it is confined to the water which escapes or seeps from ditches, canals, reservoirs, and irrigated lands.

In the orchards of southern California seepage water is of insignificant amount and of minor importance, for the reason that little water is allowed to escape. Through the use of cemented ditches and closed pipes the water is conveyed without loss from the source to the orchard tracts. The same economy is practiced in its application to the fruit trees. By frequent cultivation evaporation is diminished, and the skillful irrigator endeavors to produce the desired results with the minimum quantity of water. In the Rocky Mountain States the conditions are quite different. Water is much more abundant. Instead of using impervious channels, such as lined canals and closed pipes, water is conveyed in open ditches over porous formations of loose earth and gravel. The mode of irrigating known as flooding is usually practiced, not because it is the most economical of water, but because it is the cheapest. In view of the fact that large volumes of water are daily diverted and applied to dry soil during the summer season in such a manner as to admit of a large percentage of waste, it is not surprising that this waste or seepage water becomes an important factor in the irrigation of a district.

SEEPAGE FROM IRRIGATION CANALS.

Whenever water is conveyed in channels excavated in ordinary soils and subsoils, a large percentage of the flow is absorbed by the porous materials forming the bottom and sides of the channel. In the past, writers on irrigation have frequently attributed this loss to both evaporation and seepage. This may account for the false impression that prevails among irrigators as to the real cause of the loss. Many claim that it is chiefly due to excessive evaporation. This was the belief of an intelligent water master whom the writer met last summer. This man, after thirteen years of continuous service in operating a canal, had reached the conclusion that the loss in conveyance, which formed about one-third of the total flow, was due almost wholly to evaporation.

As a matter of fact, the loss due to evaporation was so small when compared with that from seepage as to be scarcely worth mentioning. On this particular canal the quantity of water evaporated during a hot day in midsummer is equivalent to the continuous flow of 1 cubic foot per second for the same period, while the quantity which was lost by seepage amounted to about 75 cubic feet per second. In other words, the loss due to seepage was seventy-five times greater than

that due to evaporation. It is true that a large part of the water used in irrigating is evaporated, but this takes place after the water has been spread out on the fields and not to any great extent while it is confined in the canal.

This fact should be clearly understood by the irrigators, otherwise the defects in existing canals will not soon be remedied. So long as the owners believe that the loss of water is principally due to evaporation, over which they have practically no control, they will be content to let things alone. Whereas, if the truth is made clear to them that evaporation from the surface of their canals is insignificant and that from fifty to a hundred times more water escapes through the lining of the bottom and sides, they will realize that this great loss may be in a measure prevented and that the stream which now waters only 75 acres may, if conveyed in a more impervious channel, supply water for 100 acres.

LOSS DUE TO SEEPAGE IN GALLATIN VALLEY.

West Gallatin Irrigation Canal.—This canal diverts water from the West Gallatin River, in Gallatin County, Mont. Its intake is near the mouth of the canyon of the same name, and its general course is northwesterly. In capacity, original cost, and total length, this canal takes precedence over all others in Gallatin Valley.

For the first quarter of a mile it runs parallel to the river in deep cuttings and considerably below the bed of the river to obviate the necessity of constructing and maintaining a diversion dam. This portion was excavated to a width of 24 feet, on a grade of 10.56 feet per mile. At its lower end are placed secondary gates with waste gates to allow the surplus water to flow back into the river. Owing to the rapid descent of the river the canal soon reaches the left bank of the narrow river valley, and thence extends along the steep hillside in a continuous series of sharp curves which the numerous ridges and deep ravines necessitate. The formation varies from a loose vegetable loam on top to sand, gravel, and bowlders beneath, overlying a soft sand rock which is locally termed mud rock. The softer portions of this sand rock are readily disintegrated by seepage water from the canal, and the harder portions frequently form the bed of the graded canal, so that it is difficult to prevent the water from percolating between the subsoil and the rock formation. These unfavorable conditions have caused a considerable number of bad breaks in the upper 10 miles, and increase the loss due to seepage.

At the time of construction it was the intention to build the main canal, with the exception of the first quarter of a mile, with a bottom width of 14 feet, with side slopes in excavation of one to one, and a grade of a trifle over 3 feet per mile. The action of the water, however, in ten years, has produced many changes. Owing to the deposits of material at the inner edge and the placing of riprap on the outer slope, the width is now reduced in many places to less than 12 feet.

In the ninth mile from the intake a tunnel 241 feet long was excavated to avoid a long detour around a ridge. This tunnel is 12 feet wide and about 6 feet high, on a steep grade.

Twenty-three miles from the head the canal divides into what is known as the Green Lateral and the Hammond Canal. The Hammond Canal extends from the division gates a distance of 9 miles to what is known as the "Drop," where the grade descends rapidly through a fall of 300 feet to the head of Camp Creek. From the foot of this drop the canal is again diverted on grade, and is called Camp Creek Lateral, to its present terminus, near the thirty-ninth milepost from the headgates on West Gallatin River.

The accompanying table shows that the loss from seepage and evaporation throughout the entire length of the main canal, a distance of 38¾ miles, was 38.08 cubic feet per second, or 33 27 per cent of the quantity diverted from the river, and the average loss of the total supply in each mile of canal was 0.87 per cent.

Loss by seepage and evaporation from West Gallatin Irrigation Canal.

Date.	Length of section.	Length of wetted perimeter.	Width of water surface.	Volume received at upper end of canal section.	Volume diverted by laterals.	Volume discharged at lower end of canal section.	Volume lost in section of canal.	Percentage of total supply lost in section.	Percentage of water entering section lost in section.	Loss per mile.
	Miles.	*Feet.*	*Feet.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per ct.*	*Per ct.*	*Per cent.*
July 18	3	21.97	16.72	114.45	....	107.68	6.77	5.92	5.92	1.97
July 18	2	19.1	12.55	107.68	....	98.71	8.97	7.83	8.33	4.17
July 19[1]	4	20	13.70	98.71	....	99.56	[2].85	[2].74	[2].86	[2].22
July 19	14	17.15	12.45	99.56	46.83	37.85	14.88	13	14.95	1.07
July 20	9	12.47	9.77	37.85	6.71	27.98	3.16	2.76	8.35	.93
July 20	[3]2	13.42	11.9	28.11	11.96	11.47	4.68	4.09	16.65	8.33
July 20	4.75	14.2	13.5	11.47	....	11	.47	.41	4.10	.86
Total	38.75	....	....	....	....	....	38.08	....	....	......

[1] Measurement at head of this section taken on the evening of July 18 and at the foot the next morning.
[2] Gain.
[3] Received 0.125 cubic foot per second from Camp Creek.

Farmers Canal.—This canal diverts water from the West Gallatin River near the town of Salesville, in Gallatin County, and extends in a northwesterly direction for a distance of 12½ miles, terminating near the western boundary of the city of Bozeman. It was incorporated September 26, 1890, under the name of Excelsior Canal, with a capital stock of $50,000. The stockholders were all farmers who expected to use their water on their respective farms. The original claim was made for 5,000 Montana statutory inches, but in the fall of 1890, when about half of the canal was completed, the company learned that its capacity was far in excess of the claim. In order to utilize the volume conveyed and to conform to legal requirements, the same parties organized a second company, called the Farmers' Canal Company,

which was incorporated December 23, 1892. This latter corporation purchased the water right, right of way, improvements, and other interests of the former company and increased their appropriation to more than double that first claimed.

The canal from the main headgates on West Gallatin River to Bear Creek Slough, where a second set of headgates is inserted, has a fall of one-half inch to the rod. From the lower headgates the route follows an old mill ditch on a grade of three-eighths of an inch to the rod, and from the old mill site to the end the bottom width is 22 feet, on a grade of one-twelfth of an inch to the rod. From the upper headgates to the old mill site, a distance of 1¾ miles, the formation beneath the shallow soil is gravel, cobble rock, and bowlders. The measurements made to determine the loss from seepage did not include the upper portion of the canal where this porous formation exists, but extended from a point 1.75 miles from the head to the end of the main canal, a distance of 10.75 miles. This part of the canal traverses a fertile portion of the Gallatin Valley, where the soil for the most part is a clayey loam and reasonably deep. The loss as given in the following table is therefore comparatively small.

On July 30, 1900, the quantity flowing past the bridge at Story's old mill was 133.1 cubic feet per second, and the loss in 10.75 miles was 23.59 cubic feet per second, or 17.72 per cent of the total flow at the place named, making a loss of 1.65 per cent per mile.

Loss by seepage and evaporation from Farmers' Canal.

Date.	Length of section.	Length of wetted perimeter.	Width of water surface.	Volume received at upper end of canal section.	Volume diverted by laterals.	Volume discharged at lower end of canal section.	Volume lost in section of canal.	Percentage of total supply lost.	Percentage of water entering section lost in section.	Loss per mile in section.
	Miles.	*Feet.*	*Feet.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per ct.*	*Per ct.*	*Per cent.*
July 30	2.25	20.4	16.7	133.10	8.44	108.61	16.05	12.06	12.06	5.36
July 30	4.25	21.7	16.5	108.61	....	104.49	4.12	3.09	3.79	.73
July 31	4.25	17.17	13.5	[1]105.04	67.44	34.18	3.42	2.57	3.26	.77
Total	10.75						23.59			

[1] Received 0.55 cubic foot per second from other sources.

Middle Creek Canal.—On July 10, 1899, measurements were made on the main branch of this canal from the head down to where it branches into the North and East forks. These measurements showed that of a total of 98.9 cubic feet per second received through the headgates, 21.5 cubic feet per second were lost in transmission.

The measurements in 1900 were made on the branches as well as the main canal. Of a total quantity of 63.04 cubic feet per second admitted on July 27, 12.24 cubic feet per second were lost in the main canal between the headgates and the forks. In the North Fork

there was a flow at the head of 8.99 cubic feet per second on July 28, and the aggregate of all the diversions of water from the branch was 11.76, showing a gain of 2.77 cubic feet per second. This is due to the fact that the seepage in this portion is more than counterbalanced by the waste water which flows into it from the adjacent irrigated fields. In the East Fork there was a slight loss, showing that the flow of seepage and waste water into the canal was less than that which escaped through the sides and bottom of its channel. The results of these measurements are given in the following table:

Loss by seepage and evaporation from Middle Creek Canal.

Date.	Length of section.	Length of wetted perimeter.	Width of water surface.	Volume received at upper end of canal section.	Volume diverted by laterals.	Volume discharged at lower end of canal section.	Volume lost in section of canal.	Percentage of total supply lost.	Percentage of water entering section lost in section.	Loss per mile.
	Miles.	*Feet.*	*Feet.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*	*Per cent.*	*Per cent.*
June 27	4	10.1	8.5	63.04	31.19	[1] 19.61	12.24	19.41	19.41	4.85
June 28	2.5	5.5	4.95	[2] 8.99	11.76	....	[3] 2.77	[3] 4.39	[3] 30.81	[3] 12.32
Do	2	6.3	4.35	[4] 10.62	10.20	....	.43	.68	4.05	2.03
Total	8.5	....	....	....	....	....	9.90	....	....	....

[1] North Fork, 8.99, and East Fork, 10.62 cubic feet per second.
[2] North Fork.
[3] Gain
[4] East Fork.

YELLOWSTONE COUNTY.

The Big Ditch.—This canal was begun in 1882 by the Minnesota and Montana Land and Improvement Company, and completed several years later at a total cost of $110,000, of which sum $40,000 was expended on fluming. Under the able supervision of Mr. I. D. O'Donnell the flumes across ravines have in nearly every case been replaced by earthen embankments, so that the cost of the fluming now in place would not exceed $3,000. This wise change in construction will annually save a large sum of money in repairs and maintenance. The canal as originally built was to be 30 feet on the bottom over the upper portion, with side slopes of 1 to 1, a water depth of 3 feet, and grade of 2.5 feet per mile. The action of the water and atmosphere in fifteen years has made many changes.

The measurements to determine the losses from seepage were made on that portion of the canal lying between Tilden's ranch and the Hesper farm, with an intermediate measurement at Park City. The length of the upper section was 6 miles, that of the lower 16 miles. The character of the soil from the headgates to Tilden's ranch, a distance of 5 miles, is porous, consisting chiefly of sand and gravel; between Tilden's ranch and Park City it is sandy loam. Below Park

FIG. 1.—MAIN HEADGATES OF REPUBLICAN DITCH ON BITTER ROOT RIVER.

FIG. 2.—SECONDARY GATES WITH SPILLWAYS CONTROLLED BY FLASHBOARDS, REPUBLICAN DITCH.

GAGING STATION NEAR HEAD OF REPUBLICAN DITCH.

City, for about 5 miles, it is a heavy clay soil, and beyond it is again a light sandy loam to the terminus of the canal.

The results as summarized in the following table show that on August 9, 1900, 254.47 cubic feet per second or 10,179 Montana miner's inches passed the upper gaging station, and of this amount, 16.83 cubic feet per second were lost between Tilden's ranch and Park City, a distance of 6 miles, and 48.22 cubic feet per second in the following 16 miles. These make a total loss of 65.05 cubic feet per second in 22 miles, or 25.56 per cent of the total flow:

Loss by seepage and evaporation from Big Ditch, Yellowstone County.

Date.	Duration of experiment.	Length of section.	Length of wetted perimeter.	Width of water surface.	Volume received at upper end of canal section.	Volume diverted by laterals.	Volume discharged at lower end of canal section.	Volume lost in section of canal.	Percentage of total supply lost.	Percentage of water entering section lost in section.	Loss per mile.
	Hrs.	*Miles.*	*Feet.*	*Feet.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*	*Per cent.*	*Per cent.*
Aug. 9 and 10	48	6	31.25	29	254.47	24.76	212.88	16.83	6.61	6.61	1.10
Aug. 10 and 13	60	16	29.5	26.2	212.88	72.18	92.48	48.22	18.95	22.65	1.42
Total		22						65.05			

BITTER ROOT VALLEY.

The Republican Canal, Ravalli County.—Prior to last spring no accurate data had been obtained in regard to the volume of water carried in this canal and the percentage of loss due to seepage, nor had any accurate means been used to divide the flow pro rata among the stockholders. One of the objects that the writer had in view in making measurements on this canal during the past season was to introduce into this part of the State improved methods of distributing water. So long as the loss due to seepage and evaporation in 12 miles of main canal was unknown, any attempt to apportion the water equitably among the stockholders would be mere guesswork. Knowing the net flow available after all losses in conveyance are deducted, it becomes only necessary to devise suitable measuring devices which will give to each lateral its proportionate share.

The results of the measurements made in July, 1900, to determine the loss from seepage are given in the following table. The loss in the first section, from the head to the town of Grantsdale, 3.6 miles, is 34.34 cubic feet per second; that in the next section, from Grantsdale to the lower end of the Corvallis ranch. 6.8 miles, is only 0.35 cubic feet per second, while the loss in the remaining section, to the end of the main canal at the Cowan headgate, is only 0.66 cubic feet per second. These figures show that the greater part of the loss

occurs in the upper third of the canal through the gravelly formation extending from the headgates to the north line of the town of Grantsdale.

Loss by seepage and evaporation from Republican Canal.

Date.	Duration of experiment.	Length of section.	Length of wetted perimeter.	Width of water surface.	Volume received at upper end of canal section.	Volume diverted by laterals.	Volume discharged at lower end of canal section.	Volume lost in section of canal.	Percentage of total supply lost.	Percentage of water entering section lost in section.	Loss per mile.
	Hrs.	*Miles.*	*Feet.*	*Feet.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*	*Per cent.*	*Per cent.*
July 21	24	3.6	17.87	12.75	120.49	9.31	76.84	34.34	28.52	28.52	7.92
July 23	24	6.8	12.37	9.75	76.84	64.75	11.74	.35	.29	.46	.07
July 24	12	1.2	9	8	11.74	11.08	....	.66	.55	5.62	4.98
Total	......	11.6	......	......	....	....	....	35.35	......	......	......

CONDITIONS AFFECTING SEEPAGE FROM CANALS.

Until recent years the question of loss from irrigation canals received little attention. The owners sought to excavate a channel of sufficient cross section and fall to carry the desired quantity of water, but when this was accomplished they gave little heed to the large volume which was lost in flowing through the canal. If even a small fraction of this loss had escaped over the top of a low embankment where the ditch rider could have observed it, the defect would have been remedied at once; but because the escaping water percolated the porous bottom of the channel unobserved and without any visible effects on the surface near the right of way of the canal, it was permitted to flow on undisturbed. This problem, like many more connected with irrigation, is too complicated for the ordinary irrigator or canal owner to solve. It belongs by right to the scientific bureaus of the nation and to the experiment stations of the West.

Character of the channel.—The nature of the soil through which a canal is built greatly affects the loss by seepage. If it be composed for the most part of clay there will be but little loss from this cause. If, on the other hand, the material be either sand or gravel the loss may be very great. In the building of canals the source of supply, the route, and the carrying capacity are carefully considered, but if the knowledge gained from other canals excavated in like material goes to show that 50 per cent of the water entering the headgate is likely to be lost by seepage, this one feature may become of first importance. The great need at the present time is for more accurate data in relation to the seepage from canals now in operation, so that when a new enterprise is planned and the materials along the route of the proposed canal examined it will be possible to predict within

certain limits what the loss from seepage will be. If, for example, a conclusion, based on accurate data, were reached that the proposed canal would lose by seepage 30 per cent of its entire flow, either the route should be changed or the style of construction modified so as to render the channel more impervious. In the past men have built canals along sandy and gravelly side hills, knowing that the loss would be excessive at first, but hoping that the sediment borne by the water would in time fill up the interstices between the particles of the coarse material. There is no question but that this change is gradually brought about, provided the velocity of the water is such as to admit of the deposition of sediment.

Twenty-eight years ago a canal known as the Utah and Salt Lake Canal was built from a place on Jordan River known as the Jordan Narrows, and extended for a distance of about 28 miles in a northerly direction toward Great Salt Lake. The bottom width was 30 feet near the head, and over the greater part of its length the fall was 18 inches to the mile. Soon after the canal was completed and in operation measurements showed the loss to be about 50 per cent of the flow through the headgates. Twenty-one years later the author, by making about sixty measurements, found the loss to be 22 per cent. This canal may be taken as a type to represent a large number. The figures given above go to show that with a slight grade the open spaces through which the water percolates will in time become filled with sediment. He who waits on nature's remedy, however, may wait too long. Water is becoming too valuable to be wasted in such large quantities. In the case above referred to the loss at the end of twenty-one years was 40 cubic feet per second, or 1,600 Montana inches.

Velocity of the water.—The rate at which water moves in a canal has much to do with the porosity of the channel and the consequent loss by seepage. Many irrigators are of the opinion that if they can convey water over loose, gravelly formations at a high rate of speed the loss by seepage will be much reduced. There would seem to be little truth in this theory. When the velocity is too great the sediment and finer particles of soil are carried down by the current, leaving a bed of well-washed gravel and cobble rock; and it is a well-known fact that when a channel becomes eroded by the action of water the loss by percolation is greatly increased. About all that can be stated in favor of this theory is that a body of water flowing at a high velocity requires a much smaller channel than a similar body flowing at a low velocity, and that, other things being equal, the loss is proportional in a way to the size of the channel; and it is also true, as will be noticed hereafter, that the greater the depth of water the greater will be the percolation, and in increasing the size of the channel the depth will probably be increased. On the other hand, the results of measurements show that the loss by percolation around the

perimeter of a canal on a steep grade and eroded by the action of water is much greater than it would be if the grade were reduced, the velocity low, the bed lined with sediment, and the cross section increased.

Much of the loss due to seepage from the canals in this State is traceable to the injurious effects of steep grades, high velocities, and channel beds that are scoured clean of all sediment and clay. Laterals have been built on the natural slope of the country, irrespective of the fall. In many instances the fall is from 50 to 100 feet per mile, and the effect of the high velocity thus produced is to wash away the bed until a porous, rocky formation is reached. In places where the soil is deep the effect of the current is to undermine the banks, which cave in and are washed downstream, thus forming wide and deep chasms through cultivated farms that detract much from their appearance and value.

One of the most difficult tasks in canal construction is to adjust the grade in such a way that the water will move neither too rapidly nor too slowly. Some of the injurious effects of too high velocities have been noted; those resulting from a sluggish current are the lessened carrying capacity, the gradual formation of sediment until the channel is much reduced in area, and the growth of aquatic plants. Experience has shown that in ordinary soils a mean velocity of from 2.5 to 2.75 feet per second may be used without incurring any risk of filling the canal with silt, or, on the other hand, of having the bottom scoured by too rapid a current.

Manner of building.—There is usually a right and a wrong way of doing things, and canal building is no exception to this rule. If built in the wrong way the owner pays yearly tribute to the defects in the original construction, in the form of water lost by seepage. A common defect is to form the embankments on top of the original surface without first plowing up the sod or removing the weeds and sagebrush. The result is a leakage along the original surface whenever the water in the canal rises above the excavated portion. The surface beneath the embankments should first be plowed deep, all vegetable matter removed, and a water-tight joint made between the made embankment and the natural soil.

In the early days of irrigation in Colorado, when the author first went to that State, canals were built in much the same way as cellars were dug. The sole aim seemed to be the removal of the earth from the canal site, to be heaped up on the edges without any regard to either appearances or utility. Experience has since taught the irrigators of the West that every yard excavated should be made to serve the double purpose of making a channel and forming an embankment. To accomplish this end the top of the embankments should be as regular and as true to grade as the bed of the canal. The sole

purpose of a canal is to convey water from one place to another, but if one-third seeps through the bottom and sides along the route the usefulness of such a canal may be called in question. It is not enough that we merely provide a channel for the water to flow through; we should also ascertain if it will hold water. If not, the proper time to remedy so serious a defect is when the canal is being built. It costs but a trifle more to excavate the bed a few inches below grade, and fill the space thus made with good puddle. If this were done at the worst places along the route the value of the water thus saved in one season would frequently pay for the extra cost involved.

Volume of water conveyed.—The loss from seepage usually varies more or less directly with the volume carried. When water is first turned into new ditches and canals the loss may be excessive for the first season, but in time, if the grades have been properly adjusted, a coating forms over the bottom and sides which diminishes the loss. If the water is held at the same level for a number of seasons there will be little change in the volume lost by seepage. As soon, however, as the water in the canal is raised, the pressure is not only increased, but new surfaces uncoated by silt come in contact with the water and increase the loss. This fluctuation in the quantity of seepage water makes it difficult to apportion the water equitably among shareholders. Except in the case of old canals, the area of land watered by each is annually increased, and every additional acre reclaimed calls for an extra supply of water. This yearly change is after all perhaps not so important as the fluctuations during the irrigation season. Only a small amount may be turned in at first, but as the season advances the supply is gradually increased until a full head is reached. This full head is maintained until the crop begins to mature, when a portion is turned off and the supply is gradually reduced until there may be only enough left in the canal to water stock. This gradual increase in the volume carried in the spring, followed by a gradual decrease in the fall, causes a corresponding fluctuation in the quantity which seeps through the bottom and sides of the canal.

In view of the conditions named above, it would be difficult to determine, for each definite volume carried, the percentage of loss. The most that can be expected is the making of tests during periods of maximum flow. The results will enable the superintendent or ditch rider to allow the necessary amount for waste and apportion the balance to the rightful owners at a time when all the water is needed. The amount wasted in spring or fall when the canal is only partly filled is less important, for the reason that there is no scarcity of water. The supply is then adequate for all demands. Measurements of seepage should therefore be made with a full head, in order that the greatest loss may be known, and the total flow diminished by this loss would represent the volume available at the headgates of the farmers' laterals.

In conclusion, the author takes pleasure in acknowledging the able assistance rendered by Prof. J. H. Gill, M. E., in calculating the results of stream measurements and in preparing the necessary drawings. Messrs. H. B. Waters and W. B. Freeman, students in engineering of the Montana Agricultural College, did careful work in collecting field data during the summer season. Acknowledgments are also due for the valuable aid rendered gratis by Mr. I. D. O'Donnell, of Billings; Mr. George Watt, of Park City; Mr. E. C. Kinney, M. Am. Soc. C. E., of Bozeman; and Messrs. B. McGinty, P. A. Shannon, and M. D. Kippen, of Hamilton, Mont.

PROGRESS REPORT ON SILT MEASUREMENTS.

By J. C. Nagle, C. E.

LOCATION.

The observations here reported were made mostly on the Brazos and Wichita rivers, Texas. The Brazos River was selected because of its accessibility to the writer, the observations being made at a point 6 or 7 miles west of College Station, where the county road crosses the river by means of a highway bridge known locally as the "Jones Bridge." While it is not likely that storage reservoirs will ever be built on the Brazos near the point at which the observations were made, it is possible to construct them on the upper reaches of the river, and the observations made at the former point would be of value for the latter localities.

The Wichita River was selected because an extensive irrigation system in which the storage of water is contemplated has been projected on that stream. (See p. 323.) But the fact that the waters of this river carry excessive quantities of silt at flood times has caused apprehension lest the storage reservoir should be filled up before the results obtained would justify the expense involved in the construction of the system, and hence the immediate desirability and importance of silt measurements on this river. It was originally intended to have observations made at the site of the proposed reservoir, about 40 miles above Wichita Falls, but the inaccessibility of the point caused the abandonment of this intention and the observations were made only at Wichita Falls, save for the collection of two sets of samples at the proposed dam site.

METHODS.

The method of investigation consisted in measuring the quantity of silt precipitated by a sample of water and determining the ratio of this silt to the water sample volumetrically. The measurement of the total discharge of the stream admits of a computation of the total amount of silt carried during any given time.

Usually 4 samples of water were taken at each sampling. One was taken from the top, 1 from near the bottom, and 2 from intermediate points, so as to determine, if possible, the relative quantities of silt carried at different depths. These samples were poured into calibrated glass tubes about 1 inch in internal diameter to a depth of 20 inches, and allowed to stand for one week, when the depth of sediment at the bottom was measured and the appearance of the water

noted. At first an accurately graduated scale was used to measure the depths of sediment, but with small amounts this was found to give too high percentages, so that during 1900 the silt has been first allowed to settle to the bottoms of the tubes, after which the water is decanted and the silt transferred to small, narrow tubes, graduated to cubic centimeters and fractions thereof. Enough water is used in transferring this sediment to take it all over and fill the small tubes to a depth of about 7 inches. In these smaller tubes the percentages are lower than when measurements are made in the large tubes, even when the depths of sediment in the latter are read to thirty-seconds of an inch. It was the original intention that a second set of tubes should also be filled and allowed to stand for one month to find how much further settling took place in the sediment, but this was not practicable, partly on account of the great number of tubes required. Portions of each sample were also to be reserved for a month, and at the end of that time to be mixed and turned over to a chemist for analysis to determine more accurately the amount of sediment and its fertilizing or injurious properties. This was, however, done in only a few cases, as will be explained farther on.

The samples of water were taken with cans having a diameter of about 2 inches, and an effective depth of about 12 inches. The bottoms are indented and have a loop soldered to them, to which a sinker is attached. At the top is a bale, and the rubber stopper has a ring attached, to which a cord may be tied. The can is lowered to the desired depth and the cork withdrawn. Since the early part of May, 1900, however, the writer has made use of a specially designed water sampler. This sampler consists of a horizontal brass barrel or drum with gates at the ends, which are suddenly closed by springs when a cord that is attached to spring catches is pulled. It requires a vane to keep it end on to the stream in taking a sample.

A gage rod was set on each stream and the daily gage heights read and recorded as far as possible. The areas of cross sections were obtained by soundings from the Jones Bridge on the Brazos, and from the highway bridge, about one-half mile north of Wichita Falls, on the Wichita. The character of the beds of the streams being such that scouring easily took place, it was necessary to measure the cross section each time a gaging was made.

Previous to January, 1900, the velocities of the streams were determined by float measurements, and since that time with a current meter.

DISCHARGE AND SILT MEASUREMENTS.

BRAZOS RIVER.

The flow in Brazos River at the Jones Bridge, where the observations were made, is perennial. Drainage toward the Brazos begins in Guadalupe County, N. Mex., but the flow of the feeders across the

Llano Estacado, or Staked Plains, is very uncertain until well down toward the lower edge of the plains. The drainage basin of the Brazos contains approximately 37,400 square miles, as measured on a topographic map with a planimeter. It may be separated for the purpose of this discussion into four divisions, which, with their areas, determined in the same manner, are as follows:

Division A, including all that apparently contributory portion of the great plains situated above the 3,000-foot contour, and approximately on a line drawn from Floyadada to Midland. Area, approximately, 7,250 square miles.

Division B, including that portion of the contributory area lying below the lower scarp of the great plains and above the junction of the Clear and Salt Forks of Brazos River, with all the tributaries to these streams. Area, approximately, 12,900 square miles.

Division C, embracing all that territory the waters from which find their way into the Brazos below the mouth of Clear Fork and above Waco. Area, approximately, 6,900 square miles. The dividing line between divisions B and C passes just to the east of Cisco and perhaps 4 miles east of Breckenridge.

Division D embraces all that area tributary to the Brazos below Waco and above the Jones Bridge. Area, approximately, 10,350 square miles. The largest tributary in Division D is Little River, which is called Leon River higher up toward the source. This stream receives the first inflow in the vicinity of Cisco.

The Hydrographic Division of the United States Geological Survey has a gaging station at Waco, Tex., from which, when the records for 1900 shall have been published, it will be possible to ascertain the discharges at that point, so that by taking these discharges from the corresponding discharges at the Jones Bridge it will be possible to determine the amount contributed by the area included in Division D. It seems probable that Division A contributes very little to the flow in the lower reaches of the river, though no definite information upon this point is at hand.

The first observation on this river was made May 29, 1899. Samples of the water were taken and the discharge of the river was determined. A gage rod was prepared for use on Brazos River, but the unusual floods which occurred in the latter part of June, 1899, and continued for weeks, rendered it impossible to set this rod until the 1st of August following. During this time, however, beginning June 19, the depth of the river was measured once a day. Since August 1, 1899, daily readings have been taken except during the interval from September 10 to October 9, 1899. The river continued very low during this time, however, and it has been possible to interpolate approximately for these missing readings. The high water which occurred during the latter part of April, 1900, carried away the wooden drift guards to which the gage had been attached. This loss

necessitated a resort to a new device for measuring the depth of the stream. A small can was partly filled with molten lead and attached to a small chain to which copper tags properly numbered were fastened at 1 foot intervals. The links of the chain were each one-half inch long, which fact rendered it possible to read fractional parts of a foot. In making a measurement the can is lowered until its bottom just touches the surface of the water, and the depth below a certain point on the bridge is noted. The gage heights have been kept in consecutive order measured from the same point on the bridge.

Discharge measurements were made on the dates given below with the results as given in the table.

Measured discharges of Brazos River, Jones Bridge, west of College Station, Tex.

Date.	Gage height.	Discharge.	Velocities measured by—
	Feet.	*Cubic feet per sec.*	
May 20, 1899	....	2,310	Floats.
June 19, 1899	....	6,650	Do.
July 14, 1899	....	7,950	Do.
Sept. 10, 1899	1.7	574	Do.
Feb. 3, 1900	4.4	2,457	Current meter.
Mar. 3, 1900	2.85	1,130	Do.
Apr. 1, 1900	8.4	7,796	Do.
Apr. 29, 1900	41.6	123,700	Do.
May 12, 1900	9.6	9,890	Floats.
June 3, 1900	31.0	54,900	Current meter.
July 12, 1900	2.4	1,610	Do.
Aug. 4, 1900	5.9	3,466	Do.
Sept. 23, 1900	12.6	15,040	Do.
Oct. 21, 1900	3.4	1,870	Do.
Nov. 18, 1900	3.0	1,720	Do.

At high stages of the river it was impossible to get the current meter much below the surface of the water on account of the very swift current, so that only surface velocities could be taken on such occasions. When this was done the mean velocity in each vertical section was taken as nine-tenths of the surface velocity. Sometimes drift interfered with the working of the meter near the axis of the stream, so that even the surface velocities at these points had to be approximated or determined by float measurements.

Before securing the current meter it was often possible to take surface velocities only at the axis of the stream. In such cases the mean velocity of the stream was taken as 0.81 of the axial surface velocity. The measured discharges from September 10, 1899, to November 18, 1900, and the gage readings as given above were platted, and a compromise rating curve was drawn. It was not possible to make the curve pass through all the points. The channel of the river was scoured out by every large flood and gradually silted up again at periods of low water. These changes in depth in many instances amounted to as much as 6 feet and in one spot to 10 feet. This last was caused by the lodging above the bridge of an old tree which had fallen in with a caving bank. Figure 28 shows the changes in the cross section of the river for ten measurements, and an inspection of

this will show that to use the compromise rating curve in all cases would be likely to result in considerable variations from the actual discharges. Large-scale curves were drawn to pass through points resulting from the platting of measurements made between floods, and in some cases direct interpolation was resorted to to get the daily discharges given below. It was sometimes a question as to which points should be joined in getting these large-scale rating lines, but the cross sections taken at the times the gagings were made served to furnish a guide for the judgment in making the decision. The gagings

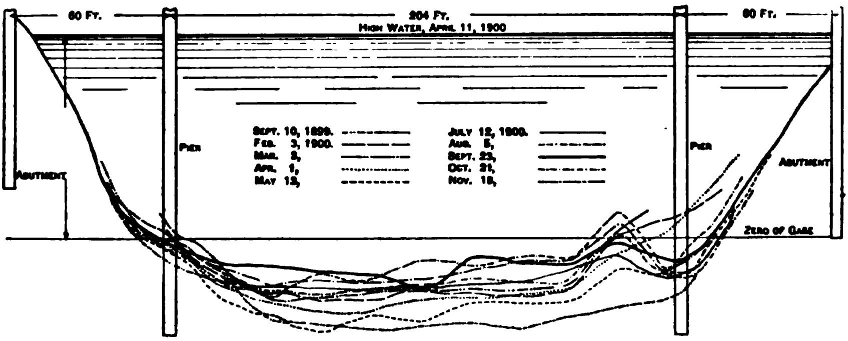


FIG. 28.—Cross sections of Brazos River at Jones Bridge.

were too few in number to enable one to make up rating curves for each interval of change in the river channel, and for all high stages of the river the discharges as determined from the compromise rating curve had to be employed.

On account of the many cases in which interpolation had to be resorted to, and because several large-scale curves had to be used for low stages of water, no rating tables were constructed from the diagram, but the daily gage heights were used as arguments and the corresponding discharges were read directly from the diagram. These discharges are recorded in the table following.

Daily discharge of Brazos River at Jones Bridge, west of College Station, Tex.

Day.	1899.					1900.										
	August.	September.	October.	November.	December.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.
	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.	Cub. feet per sec.
1	5,150	725	[1] 360	11,800	4,400	3,500	2,800	1,150	7,800	132,000	51,000	2,000	2,950	1,660	59,000	2,400
2	4,550	725	[1] 360	7,500	3,700	3,100	2,670	1,150	6,400	123,700	48,000	1,900	3,200	1,600	39,400	2,150
3	4,000	675	[1] 360	6,400	3,000	2,800	2,450	1,130	5,700	73,400	59,000	2,100	3,800	1,150	22,000	2,100
4	3,500	675	[1] 360	5,750	2,600	2,600	2,330	1,100	5,000	54,000	41,400	2,200	3,470	1,660	16,700	3,500
5	3,100	675	[1] 300	4,600	2,200	2,500	2,330	1,100	4,550	39,500	29,300	1,940	3,470	1,560	9,600	3,400
6	2,700	675	[1] 300	3,800	2,140	2,300	3,600	1,020	4,400	9,400	21,000	1,850	5,100	1,150	8,100	3,400
7	2,500	675	[1] 300	3,050	2,050	2,300	2,800	1,100	12,500	24,300	18,000	1,850	3,300	1,150	6,300	3,400
8	2,150	625	[1] 300	2,500	1,950	2,600	2,800	1,150	56,800	48,400	14,000	1,750	3,100	2,050	5,300	37,300
9	2,000	625	300	2,100	2,000	4,100	2,330	1,200	110,000	52,800	12,700	1,710	2,700	16,500	5,000	11,200
10	1,900	574	350	1,950	2,600	14,800	2,330	2,050	118,500	43,600	9,890	1,680	2,400	16,400	4,000	4,500
11	1,700	[1] 525	350	1,700	4,700	28,200	2,450	2,000	[1] 135,000	59,000	8,100	1,610	4,400	22,000	4,000	4,350
12	1,650	[1] 525	350	1,600	3,300	38,400	2,330	1,500	110,000	9,890	6,000	1,610	4,000	32,200	3,200	5,300
13	1,600	[1] 480	350	1,400	17,100	30,100	2,050	1,300	55,200	9,890	5,200	1,610	5,400	22,500	2,400	5,100
14	1,400	[1] 480	350	1,350	14,600	25,100	2,050	1,300	72,700	8,000	4,600	1,520	3,000	32,200	3,000	5,000
15	1,340	[1] 480	300	1,000	11,100	16,600	2,050	1,150	34,500	24,000	4,500	1,520	2,700	13,000	3,000	3,700
16	1,220	[1] 480	300	950	8,000	11,000	2,000	2,000	29,300	27,400	5,600	1,610	2,000	9,500	2,400	2,500
17	1,160	[1] 480	300	900	6,500	14,000	1,950	1,200	23,400	29,300	5,200	1,610	2,450	9,600	2,220	1,950
18	1,160	[1] 420	300	850	5,200	9,600	1,900	1,200	19,400	22,300	4,300	8,200	6,300	8,800	2,220	1,720
19	1,080	[1] 420	300	800	5,400	7,600	1,800	1,200	15,400	14,900	3,700	4,500	2,300	6,900	2,150	...
20	1,020	[1] 420	300	1,000	5,850	2,800	1,800	1,150	12,000	25,400	3,300	3,600	1,900	5,700	2,000	...
21	1,000	[1] 420	300	10,800	14,000	5,600	1,800	1,150	10,300	23,500	3,000	3,000	1,850	3,800	1,870	...
22	1,000	[1] 420	300	27,200	15,400	5,000	1,600	1,100	10,300	29,300	3,000	3,470	1,770	4,000	2,000	...
23	970	[1] 420	300	50,500	23,300	4,500	1,500	1,500	33,700	26,400	2,900	2,800	1,720	15,040	1,670	...
24	970	[1] 420	400	28,500	14,400	4,400	1,500	1,950	29,300	20,500	2,800	2,150	1,630	26,500	9,800	...
25	920	[1] 420	550	14,900	10,500	4,000	1,400	10,000	31,400	13,300	2,500	1,900	1,600	37,400	9,200	...
26	870	[1] 360	500	12,800	9,700	3,800	1,300	12,700	37,300	12,800	2,300	1,850	1,560	48,500	5,300	...
27	870	[1] 360	600	9,700	8,600	3,800	1,300	19,000	63,200	6,200	2,000	4,500	1,400	54,400	5,200	...
28	820	[1] 360	17,100	7,700	6,500	3,400	1,200	31,700	38,700	14,400	1,900	5,600	1,330	58,500	3,700	...
29	820	[1] 360	10,100	6,200	5,300	3,100	...	29,600	123,700	11,800	2,100	5,000	1,150	64,400	3,400	...
30	770	[1] 360	3,000	5,050	4,400	3,000	...	17,100	125,000	9,500	2,000	5,700	1,050	71,000	3,500	...
31	770	...	19,800	...	3,900	2,900	...	10,300	...	31,500	...	4,800	1,330	...	3,500	...
Mean	1,763	509	1,917	7,812	7,219	8,629	2,086	5,234	43,715	33,238	12,623	2,811	2,720	19,677	8,100	...

[1] Estimated.

The following table shows the approximate total volumes discharged per month from August, 1899, to October, 1900, inclusive, the discharges being given in acre-feet per month. These discharges were computed from the mean daily discharges per month as given above. The table also shows the run off in inches and in cubic feet per second per square mile for the discharge area. The run off is given both inclusive and exclusive of the area lying above the 3,000-foot contour (Division A). The run off is computed in the two ways because it is doubtful what the proportion of flow contributed by Division A may be. It may not contribute anything to the flow except on rare occasions, and in any event it is not likely that its contribution is at all commensurate with its area.

Computed monthly discharge of Brazos River at Jones Bridge, west of College Station, Tex.

Month.	Mean discharge.	Discharge for month.	Run off— For 37,400 square miles. Depth.	Run off— For 37,400 square miles. Per square mile.	Run off— For 30,150 square miles. Depth.	Run off— For 30,150 square miles. Per square mile.
	Cubic ft. per sec.	*Acre-feet.*	*Inches.*	*Cubic ft. per sec.*	*Inches.*	*Cubic ft. per sec.*
1899.						
August	1,763	108,410	0.054	0.047	0.067	0.058
September	509	30,290	.015	.014	.019	.017
October	1,917	117,880	.059	.051	.073	.064
November	7,812	464,850	.233	.209	.289	.259
December	7,219	443,880	.223	.193	.277	.239
1900.						
January	8,629	530,300	.252	.231	.330	.286
February	2,086	115,860	.058	.056	.072	.069
March	5,234	321,830	.161	.140	.200	.174
April	43,715	2,601,200	1.304	1.169	1.618	1.450
May	33,238	2,043,700	1.025	.888	1.271	1.102
June	12,623	751,120	.377	.338	.467	.419
July	2,811	172,840	.087	.075	.107	.093
August	2,720	167,250	.084	.073	.104	.090
September	19,677	1,170,900	.587	.526	.728	.653
October	8,100	498,100	.250	.217	.309	.269
Total 15 months		9,538,410	4.769	4.227	5.930	5.242
Total from August, 1899, to July, 1900, inclusive		7,702,160	3.848	3.411	4.789	4.230

The following table shows the results of measurements made of the Brazos River water in order to determine the percentage of silt carried in suspension. These results were obtained by allowing the samples to stand in the tubes one week. A few, however, were allowed to stand a month, and these were found to shrink about 10 per cent on an average.

The table also shows, in the ninth column, the total silt in cubic feet per second as determined from the settling measurements at the end of the week, these quantities being computed from the values given in the seventh and eighth columns. In the tenth column the appearance of the water has been noted, if a record of it was kept, and in the eleventh column is given the time it took the sediment to

settle and leave the water clear enough so that one could see objects, such, for instance, as long-primer print, with a fair degree of clearness, on the other side of the settling tube in good light.

Silt determinations for the Brazos River.

When collected.	Silt in water. Surface.	One-third depth.	Mid-depth.	Two-thirds depth.	Bottom.	Mean	Discharge.	Total silt.	Appearance of water.	Time required to settle clear.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*		*Hours.*
May 29, 1899	4.65	4.32		4.67	4.45	4.52	2,310	104	Red	
June 19, 1899	1.68	2.16		2.25	2.01	2.03	6,700	136	Dark	
July 2, 1899	.69	.77		.73	.72	.73	150,000	1,095	Dark gray	
July 14, 1899	.80	1.23		1.15	.87	1.02	7,800	80		
Aug. 3, 1899	2.10					2.10				
Sept. 10, 1899	.27	.30		.29	.29	.29	574	1.6		
Dec. 9, 1899	.16	.18		.18	.17	.17	2,000	3.4		
Jan. 2, 1900	.17	.20		.25	.21	.21	3,100	6.5		
Feb. 3, 1900	0	0		0	0	0	2,450	0	Clear	
Mar. 3, 1900			0			0	1,130	0	do	
Mar. 25, 1900	.65		.73		.60	.66	10,000	66	Dark gray	
Apr. 1, 1900	.27		.25		.29	.27	7,800	21	Light red	
Apr. 8, 1900	2.00				2.18	2.09	56,800	1,187	Very dark	
Apr. 12, 1900	1.92				2.67	2.30	110,000	2,530	Very red	
Apr. 29, 1900	1.65		1.54		1.55	1.57	123,700	1,942	Quite dark	
May 3, 1900	1.15		1.16		1.08	1.13	73,400	830	Red	7
May 6, 1900	.77	.77		.87	.81	.80	9,400	75	do	6
May 12, 1900	.63	.77		.80	.67	.72	9,890	71	Light red	7
May 13*a*, 1900	.61	.65		.82	.81	.72	9,890		Red	
May 13*b*, 1900	.66	.71		.72	.78	.72	9,890	71	do	
May 20, 1900	1.33	1.23		1.20	1.12	1.22	25,400	310	Dark	
June 3, 1900	1.44		1.36		1.43	1.41	54,900	774	do	7
June 10, 1900	.68	.58		.63	.54	.61	9,890	60	Red	8
June 19, 1900	1.11	1.17		1.11	1.04	1.11	3,700	41	Dark	7
July 12, 1900			.08			.08	1,610	1.3	Clear	2¼
July 15, 1900			.05			.05	1,520	.8	Nearly clear	2¼
July 30, 1900	2.86				2.68	2.77	5,700	158	Red	2¼
Aug. 4*a*, 1900	1.35	1.34		1.40	1.31	1.35	3,470	47	do	2¼
Aug. 4*b*, 1900	1.13	1.16		1.09	1.09	1.12	3,470	39	do	2¼
Aug. 12, 1900	.66	.68		.64	.63	.65	4,000	28	Chocolate	6
Aug. 19, 1900	.34	.31		.38	.33	.34	2,300	8	Light red	3
Sept. 13, 1900	1.03	.99		1.05	1.01	1.02	22,500	230	Red	5
Sept. 21, 1900	.74	.74		.80	.78	.77	3,800	29	do	5¼
Sept. 23, 1900	1.69	1.65		1.75	1.94	1.76	15,040	265	Very red	3
Oct. 21, 1900	.08	.08		.07	.09	.08	1,870	1.5	Light red	3
Oct. 24, 1900	3.71	3.71		3.78	4.00	3.80	9,800	372	Very red	3¼
Nov. 18, 1900	.15	.14		.15	.14	.14	1,720	2.4	Light red	3
Mean of above percentages.						1.09				

Prof. Arthur Goss[1] has allowed four samples that contained about 4 per cent at the end of a month to stand ten months longer, or eleven months in all, and has found that a further shrinkage of about 15 per cent of the volume at the end of thirty days took place. From these results it would seem that the percentages in the table should be reduced at least 25 per cent before estimating the rate of filling up of a reservoir. Perhaps a greater subsidence would occur with a longer period of time, and it is reasonable to suppose that it would.

Whenever the depth of the water was considerable, except when the water was clear, and generally when the quantity of silt was considerable, no matter what the depth of water, four samples were taken as already described. When the water was low and the quantity of

[1] New Mexico Station Bul. 34.

sediment comparatively light, only three samples were taken in a set, one from the top, one from the bottom, and one from about mid-depth. When the water was clear, only one sample was taken as a rule. Of the sets of samples taken April 8, April 12, and July 30, 1900, only two samples in each set could be used, or else were not taken because of lack of storage receptacles, and, as it happens, all three of these were heavily charged with silt.

The samples taken by the writer May 13, June 3, July 12, September 23, and the first one entered under August 4 were taken with the water sampler. The others were all taken with the tin cans already described. The set marked *a*, taken May 13, was collected in mid-stream, where the velocity was nearly 3 feet per second and the depth of water 18.9 feet. The set marked *b*, collected on the same day, was taken in 13 feet of water on the downstream side of a tree that had lodged near one side of the stream and which by reducing the velocity had caused the bottom to shoal considerably. At this point the velocity did not exceed 1.5 feet per second. The results of the two sets give the same mean quantity of silt carried, though considerable variation appears in samples taken at corresponding depths.

The means of the four sets taken with the sampler on May 13, August 4, and September 23, when averaged, show the following results:

	Per cent.
From top	1.0.8
From one-third depth	1.088
From two-thirds depth	1.173
From bottom	1.210
Mean	1.137

The means of all sets of four each, excluding the set on February 3, when no deposit was formed, are as follows:

	Per cent.
From top	1.045
From one-third depth	1.077
From two-thirds depth	1.116
From bottom	1.075
Mean of all	1.078

This would seem to indicate that the mean percentage of sediment is carried at about the one-third depth section.

Where three samples to each set were taken the means from the tables are as follows:

	Per cent.
From top	1.032
From mid-depth	1.008
From bottom	.990
Mean of all	1.010

The top samples here carried the most sediment and the percentage at mid-depth seemed to very nearly equal the mean quantity carried.

There were only five of these sets, however, as against twenty-four of those preceding, so that the former would carry greater weight. In any event, it is seen that the quantities are very variable in the different sections, and one has only to look at the water when heavily charged with silt to see that heavily charged and more lightly charged streaks of water succeed each other rapidly, due to the cross currents and eddies.

It will be noted that all the samples settled quickly, indicating that the sediment is coarse and heavy. The water was well shaken before being set away in the tubes. In all cases the water became perfectly clear in less than twenty-four hours.

Of the two samples taken on August 4, the one taken with the sampler shows slightly more sediment, but it was taken three or four hours later than the other. However, this difference in time should not have made any material difference, since the height had not changed by August 5.

It was not practicable, during these experiments, to determine the percentage of silt by weight in the water, except in two cases, which will be noted under the head of chemical analyses. Such determinations would, however, be interesting. In any question of the probable rate of filling up of a reservoir the main factor that is needed is the ratio of the volume of silt to the total volume received in a given time, provided that the total inflow is retained in the reservoir. Where a portion of the flow passes through the reservoir and is discharged by wasteweirs part of the suspended matter will be deposited in the reservoir if the velocity be materially reduced, and so far there seems to be no general method of determining just what this proportion will be.

The percentages of silt given in the tables are subject to a reduction of about one-fourth of themselves, as has already been noted, and in the case of a deep reservoir, where the pressure due to the overlying water is considerable, the silt at the bottom should become still further compacted. With the appliances at hand it was not practicable to test the effect of high pressure, but it is possible to devise an apparatus for this purpose, and it is hoped that such experiments can be made next year.

In the table which follows an attempt has been made to roughly approximate the total quantities of silt carried by the Brazos River, based upon the results given above, coupled with a rather imperfect record of the daily appearance of the river water, as noted by the observer. Could the samples have been collected daily, or even every second or third day, a much closer approximation might have been made.

Investigation has not yet shown any fixed relation of percentages of silt carried to any other factor, as flow or color of water. It is well

known, however, that when water, at least at flood stages, is red, a larger percentage of silt is generally carried than when the water is muddy or dark in color. As among waters of different degrees of redness, that which is light in color carries a small percentage of silt, and that which is very dark or deep in color carries a large percentage. This principle does not appear to apply, however, in the case of muddy waters, for among six samples collected in 1900 the only one designated as "very dark" had much the smallest percentage of silt of all. When the water is red the percentage of silt carried is generally less when the flow is small than at flood water, but this is by no means always the case. For instance, among eighteen samples taken during 1900, when the water was red, all carried more than 1 per cent of silt when the flow was above 10,000 cubic feet per second, and most of the samples taken when the flow was less than that amount showed less than 1 per cent; but among these latter are found two samples, those taken July 30 and October 24, which show the highest percentages of any taken.

Various methods were used in estimating the percentages of silt carried by the water after January 1, 1900, when record of the color of the water was first made continuously and systematically. The intervals of time given represent a continuous flow of water of the same color, as recorded by the observer. Whenever one sample was taken during such a flow the percentage given in the table for the whole period is generally the same, or approximately the same, as that given in the preceding table for the sample. When more than one sample was taken during any one period the percentage used is an average, or approximately so, of the percentages found in the samples taken. In a few cases, when no samples were taken during certain periods, the percentage of silt could be easily inferred from percentages found at other times when the condition of the water was similar in respect to color. For instance, no samples were taken between June 23 and July 3, when the water was clear, or between January 20 and 31, when it was cloudy; but the percentage given could easily be inferred from determinations made in January and February, when similar conditions obtained. In a few cases, as in the interval from May 27 to 31, when no samples were taken, interpolation was resorted to. In this case, for the period immediately preceding, the percentage of silt was estimated to be 1.20, and that during the one immediately following, 1.40. The percentage assigned for the intermediate period is the mean of these, or 1.30. In some cases mere estimates are given, as, for instance, the percentage assigned to the period from October 24 to 31, where the sample taken does not in any probability represent anywhere near the average for that period. Many of the percentages given for periods between August and December, 1899, inclusive, are also mere estimates, since at that time no record was kept of the color of the water.

Estimate of total silt carried by Brazos River.

Date.	Color.	Discharge.	Silt.	
1899.		Acre-feet.	Per cent.	Acre-feet.
August 1-15		77,820	1.50	1,167
August 16-31		30,590	.50	153
September 1-30		30,270	.25	76
October 1-27		18,720	.10	19
October 28-31		99,160	1.00	991
November 1-8		90,050	.50	450
November 9-20		30,950	.10	31
November 21-30		343,850	1.50	5,158
December 1-5		31,540	.30	95
December 6-12		37,170	.20	74
December 13-31		375,180	.50	1,876
1900.				
January 1-9	Cloudy	51,170	.21	107
January 10-19	Muddy	387,560	1.10	4,263
January 20-31	Nearly clear	91,840	.20	184
February 1-28	Clear	115,860	.00	0
March 1-24	....do	63,180	.00	0
March 25-31	Dark muddy	258,650	.70	1,810
April 1-6	Light red	67,140	.25	168
April 7-10	Very dark	590,680	2.10	12,408
April 11-21	Very red	1,025,800	2.20	22,572
April 22-30	Dark muddy	917,600	1.55	14,223
May 1-5	Red	838,200	1.13	9,472
May 6-14	....do	526,100	.74	3,893
May 15-26	Dark	533,700	1.20	6,404
May 27-31	Muddy	145,600	1.30	1,893
June 1-3	Dark	313,400	1.40	4,388
June 4-9	Red	270,550	1.00	2,706
June 10-22	Light red	130,500	.90	1,174
June 23-30	Clear	36,700	.00	0
July 1-3	....do	11,900	.00	0
July 4-17	Slightly cloudy	47,750	.07	33
July 18-26	Very cloudy	62,420	.10	62
July 27-31	Very red	50,780	2.75	1,396
August 1-4	Red	26,620	1.25	333
August 5-10	Light red	39,810	.80	318
August 11-14	....do	33,320	.65	216
August 15-31	....do	67,520	.30	203
September 1-8	Light gray	23,760	.20	48
September 9-22	Light red	401,850	.95	3,818
September 23-30	Very red	745,200	1.75	13,041
October 1-4	....do	271,950	1.70	4,623
October 5-11	Red	83,900	1.30	1,090
October 12-23	Light red	55,800	.10	56
October 24-31	Very red	86,480	1.90	1,643
Total		9,638,590		[1] 1,226,351

[1] Or 197,830,000 cubic yards.

Since the percentages given in the fourth column are from the results derived at the end of a week's settling, they should be reduced one-fourth in order to get the percentages at the end of a year's settling. Similarly the results given in the fifth column should be reduced in the same proportion. Indeed, the percentages in the fourth column represent merely an attempt to approximate the average percentage for one week's settling for the intervals opposite which they stand, and the tendency has been to throw the error above rather than below the probable true value, in order to be on the safe side.

The table covers a period from August 1, 1899, to October 31, 1900. Dividing the total silt computed for the fifteen months covered in the table by the total discharge for the same time, we get 1.28 as the approximate average per cent of silt carried by the water. Reducing this by one-fourth of itself, to allow for a settling of one year, we get 0.96 per cent as the average after the silt has stood for one year. If we exclude the last three months and consider the discharge from

August 1, 1899, to August 1, 1900, we shall get practically the same result, the difference being only one one-hundredth of 1 per cent.

WICHITA RIVER.

On some maps this river is shown as the "Big Wichita," and is so referred to by people in the vicinity of the place where measurements were made. When swollen by heavy rains it becomes a stream of considerable proportions, but ordinarily the flow is quite small, owing to the comparatively small area drained. Wichita River is formed by the junction of the North Wichita and the South Wichita rivers, about 50 miles southwest of Wichita Falls. Both branches head in Dickens County, about 120 miles in an air line nearly west of Wichita Falls, which is about 20 miles from the point at which the river empties into Red River.

The drainage area above the gaging station at Wichita Falls is about 3,050 square miles. The first observation on Wichita River was made on May 21, 1899. Besides taking samples of the water, a cross section of the river was taken and the velocity of the stream determined. On June 25, 1899, a gage rod was set on the east pier of the highway bridge at Wichita Falls. This rod consisted simply of a 1 by 4 inch board painted white and graduated to feet, tenths, and half tenths. No consecutive readings were taken on it, however, as no regular observer had been secured and as the river was rather low until about December, 1899. Floods that month damaged the rod and displaced the zero, and another rod, painted in a similar manner on 2 by 6 inch lumber, was made and securely anchored to the masonry of the west pier in February, 1900. Daily readings have since been taken on this rod.

The clear space between the end piers of the main span of the bridge, where the observations were made, is about 140 feet, and the extreme width between abutments of short end spans is a little less than 270 feet. When the gage height is not over 12 feet the extreme width can not exceed 247 feet, being held in on the north side by a masonry retaining wall. From the top of this wall the reading of the gage rod is easily discernible.

Discharge measurements were made, with results as follows:

Measured discharges of Wichita River, Wichita Falls, Tex.

Date.	Gage height.	Discharge.	Velocity measured by—
	Feet.	*Cubic feet per sec.*	
May 21, 1899		1,056	Floats.
June 26, 1899		1,153	Do.
February 10, 1900	1.80	125	Current meter.
April 23, 1900	3.05	390	Do.
July 16, 1900	1.65	61	Do.
July 19, 1900	4.40	1,588	Do.
July 21, 1900, 10.30 a.m	9.80	7,878	Do.
July 21, 1900, 5.30 p.m	12.10	16,740	Do.
September 6, 1900	2.10	210	Do.

From the discharges measured in 1900, together with the corresponding gage heights, a rating curve was constructed. The number of gagings secured, especially at high stages of the river, was not so great as would be desirable, but the expense incident to making trips to Wichita Falls prohibited a greater number being taken. Owing to sudden and comparatively large changes in the form of the bed of the river the points taken at low stages do not all lie on the rating curve, and two of them lie considerably off, but with readings in their vicinity direct interpolation was sometimes resorted to in the derivation of the quantities shown in discharge tables. These changes in the river bottom are shown in figure 29.

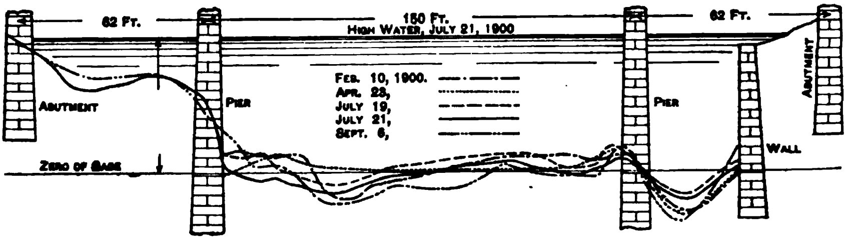


FIG. 29.—Cross sections of Wichita River at bridge at Wichita Falls.

By means of the rating curve and the daily gage readings the approximate daily discharges were determined, and are shown in the table given below. No rating table was made out because of the apparent necessity for direct interpolation in certain cases where the platted points fall off the rating curve.

Daily discharges of the Wichita River at Wichita Falls, Tex., 1900.

Day.	February.	March.	April.	May.	June.	July.	August.	September.	October.
	Cu. ft. per sec.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
1	....	110	70	5,000	2,700	240	2,600	4,700	1,050
2	....	110	70	4,300	2,160	240	2,500	4,200	940
3	....	110	60	3,750	4,600	220	2,350	3,500	1,550
4	....	110	60	3,530	3,300	200	2,300	950	2,250
5	....	90	55	3,200	3,100	200	2,200	330	1,550
6	....	90	120	3,050	2,700	190	2,530	210	1,380
7	....	90	400	2,350	2,520	430	2,450	170	1,150
8	....	90	2,350	1,950	1,850	450	2,350	90	980
9	....	90	1,700	1,700	1,580	430	2,200	60	980
10	125	70	2,200	1,500	1,500	370	2,080	2,800	....
11	125	70	6,180	1,200	1,180	310	1,850	2,550	....
12	125	70	4,200	1,050	1,020	250	1,750	2,000	....
13	125	70	2,700	920	940	220	1,550	1,780	....
14	115	70	2,160	700	800	200	1,400	1,500	....
15	115	180	1,600	650	700	100	1,380	1,150	....
16	110	400	1,400	1,150	650	60	600	1,050	....
17	110	500	1,050	920	650	60	500	850	....
18	100	500	390	850	500	60	500	600	....
19	100	400	380	800	500	1,590	480	500	....
20	100	360	385	800	400	960	480	360	....
21	100	180	385	1,150	400	[1] 10,200	480	290	....
22	100	130	390	1,080	370	6,150	460	1,150	....
23	110	120	390	920	350	3,100	440	11,600	....
24	110	110	1,020	880	350	2,700	400	8,400	....
25	110	110	950	1,100	330	2,350	400	5,550	....
26	110	100	1,100	1,150	330	16,400	210	3,550	....
27	120	100	1,500	1,280	310	9,500	200	2,800	....
28	120	100	2,160	1,850	310	5,250	270	2,160	....
29	....	90	2,180	6,180	300	3,520	210	1,550	....
30	....	90	2,000	3,750	290	3,100	210	1,150	....
31	....	80	....	3,750	....	2,620	130	....	....
Mean	112	155	1,820	2,015	1,223	2,312	1,211	2,252	....

[1] At 6 p. m., July 21, the discharge had risen to 16,740 cubic feet per second.

At high stages of the river the current is very swift. With a gage reading of 12.1, the highest stage at which the discharge was measured, the surface current at the axis of the stream was 11.8 feet per second, or about 8 miles per hour. The mean velocity of the current at this stage, however, was only 6.3 feet per second, or about 4.3 miles per hour. The discharge on July 21, given as 10,200 cubic feet per second, was for the gage reading at noon. At 6 p. m. the gage read 12.1 feet, and a discharge measurement was made at this stage with 16,740 cubic feet per second passing. The river remained at this stage but a few hours, so that 10,200 cubic feet per second represents the mean discharge for the day.

The following table gives the approximate total monthly discharges from February, 1900, to September, 1900, inclusive. It also shows the run off in inches and cubic feet per second on a basis of 3,050 square miles of drainage area.

Computed monthly discharge of Wichita River at Wichita Falls, Tex.

Month.	Mean discharge.	Discharge for month	Run off.	
			Depth.	Per square mile.
1900.	*Cu. ft. per sec.*	*Acre-feet.*	*Inch.*	*Cu. ft. per sec.*
February	112	6,220	0.0383	0.0367
March	155	9,530	.0586	.0508
April	1,320	78,550	.4829	.4328
May	2,015	123,900	.7617	.6607
June	1,223	72,770	.4474	.4010
July	2,312	142,160	.8739	.7580
August	1,211	74,460	.4577	.3970
September	2,252	134,000	.8238	.7384

The results of silt measurements are given below. The percentages given are for a settling of one week's time, and are subject to a still further reduction of about one-fourth for the percentage that would obtain at the end of a year. The percentages were found in the manner described for similar measurements on Brazos River. At high stages of the river the amount of silt is very large and, as in the case of Brazos River, it settles quickly, indicating its coarseness. The color of the water is intensely red at such times, and even after the river falls and the water becomes clear, or nearly so, the appearance, when looked at from above, is still red, due to the red sediment at the bottom of the river showing through the water.

The following table gives results of the measurements made:

Silt determinations for the Wichita River.

When collected.	Silt in water.						Discharge.	Total silt.	Appearance of water.	Time required to settle clear.
	Surface.	One-third depth.	Mid depth.	Two thirds depth.	Bottom.	Mean.				
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*		*Hours.*
1899.										
May 21	4.11		4.08		5.07	4.40	1,056	46		
June 1	5	5.70		5.80	5.41	5.48				
June 7	4.31	4.63		3.88	4	4.21				
June 11	1.54	1.61		1.40	1.41	1.49				
June 12	4.08		3.55		4.13	3.92				
June 13	3.07	2.28		2.76	2.66	2.69				
June 17, 9 a. m	3.74	3.55		3.50	3.44	3.56				
June 17, 2 p. m	2.98	2.78		2.74	2.87	2.84				
June 17, 4 p. m	2.15		2.26		2.24	2.22				
June 27	.61				.48	.55	1,150	6		
1900.										
February 10			0			0	125	0	Clear	
March 1			0			0	110	0	do	
March 15			Tr.			Tr.	180		Almost clear	
April 1			0			0	70	0	Clear	
April 13	1.72				2.97	1.90	2,700	51	Red	2¼
April 23	Tr.				Tr.	Tr.	390		Very light red.	2¼
May 1	.98			1.07	.88	.98	5,000	49	Red	2¼
May 16	3.03			3.21	3.39	3.21	1,150	37	do	3
June 1	.32				.43	.38	2,700	10	Light red	
June 15					.11	.11	700	0.7	Almost clear	2
July 1			0			0	240	0	Clear	
July 15			0			0	100	0	do	
July 19	6.64		6.85		7.03	6.84	1,590	108	Deep red	3
July 21, 11 a. m	5.52	5.10		5.59	5.78	5.50	7,880	433	do	5
July 21, 6 p. m	6.17			5.55		5.86	16,740	981	do	5
July 23	1.19	1.30		1.25	1.18	1.23	3,100	38	Red	2¼
August 1	.29		.32		.38	.33	2,600	9	do	5
August 20			Tr.			Tr.	480		Clear	
September 3	.38		.44		.38	.40	3,500	14	Muddy	12
September 6	.06		.06		.08	.07	210	0.1	Red	20

Mean of measured percentages, for 1900 .... 1.34

The percentage of silt carried at different depths is very variable, as a glance at the above table will show. For the eight sets of four samples each we have the following average results:

	Per cent.
From top	3.42
From one-third depth	3.37
From two-thirds depth	3.37
From bottom	3.34
Mean	3.375

For the set taken with the sampler July 21, the percentage of silt was greatest at the bottom. That same afternoon, however, when only two samples could be taken because the high velocity of the river made it impossible to get the sampler to the bottom of the river, the top sample showed the larger amount.

For the six sets of three samples each, excluding the sample taken July 19 at flood water, we have the following average results:

	Per cent.
From top	1.845
From mid depth	1.777
From bottom	2.047
Mean	1.890

All samples cleared rapidly when the water was thoroughly shaken up and allowed to stand, particularly when the quantity of silt present was large.

An estimate of the total quantity of silt carried by Wichita River for the eight months from February to September, 1900, inclusive, is shown in the table which follows. This must be considered as a very rough estimate because the intervals between times of taking samples is too large to give close results. The effort was made, however, to get the samples at the higher stages of the river at such intervals as would enable us to gain a fairly approximate idea of the condition of the river for intermediate days. The color or appearances of the water was also noted daily, and from these notes and the computed discharges the values shown in the percentage column have been derived, by methods similar to those used in computing the quantity of silt carried by the Brazos. For any interval, such as from the 1st to the 15th of a month, the discharge in cubic feet per second is taken from the table of daily discharges and from this the quantity of silt in acre-feet has been computed. Since the percentages in the fourth column are subject to a reduction of about one-fourth, if volumes of sediment at the end of a year are desired, the values given in the fifth and sixth column should be reduced in the same ratio.

Approximate quantities of silt carried by the Wichita River at Wichita Falls, Tex.

Time.	Appearance of water as noted by observer.	Discharge.	Approximate average of silt.	Approximate quantity of silt transported.	Approximate total silt for month.
1900.		*Acre-feet.*	*Per cent.*	*Acre-feet.*	*Acre-feet.*
February 1-28	Clear	6,220	0	0	0
March 1-31	do	9,530	Trace.		
April 1-6	do	860	Trace.		
April 7-16	Muddy	49,370	1.80	888.6	
April 17-25	Almost clear	10,590	Trace.		
April 26-30	Muddy	17,730	.60	106.4	995
May 1-6	do	45,280	.80	362.2	
May 7-11	Slightly muddy	17,260	.20	34.5	
May 12-15	Clear	6,580	0	0	
May 16-25	Muddy	19,140	2.50	478.5	
May 26-31	do	35,620	.50	178.1	1,053.3
June 1-11	do	53,920	.30	161.7	
June 12-16	Slightly muddy	8,150	.12	9.8	
June 17-30	Clear	10,690	0	0	171.5
July 1-18	do	8,390	0	0	
July 19-22	Very muddy	34,490	6.12	2,294.4	
July 23-25	Muddy	16,170	1.20	194	
July 26-31	do	80,110	1.80	1,442	3,930.4
August 1-9	do	42,600	.30	127.8	
August 10-15	Slightly muddy	19,860	.10	19.9	
August 16-31	Clear	12,020	Trace.		147.7
September 1-6	Slightly muddy	27,550	.40	110.2	
September 7-9	do	630	.05	.3	
September 10-16	do	25,450	.40	101.8	
September 17-21	do	5,160	.05	2.6	
September 22-30	Muddy	75,190	1.33	1,000	1,214.9
Total		641,560		7,512.8	7,512.8

Taking the total discharges for the period covered and also taking the sum of the quantities shown in the sixth column, we have for the two 641,560 and 7,512.8 acre-feet, respectively. Dividing the latter by the former we get 1.17 as the average percentage by volume of silt carried by the water during this time. Calling this 1.2 and reducing it by one-fourth of itself, we get 0.9 per cent as the probable average percentage of silt that would show after standing for one year. With longer settling the percentage would probably be smaller.

RIO GRANDE.

While on a visit to El Paso, Tex., during the latter part of June, 1900, the writer secured one sample of Rio Grande water, taking it with the sampler at the lower street car bridge that connects El Paso, Tex., with Juarez, Mex. Mr. W. W. Follett, who was then consulting engineer of the International (Water) Boundary Commission, kindly permitted the selection of a number of other bottles full of water that had been collected at the gaging station of the commission, about 4 miles above El Paso, and the results of these determinations are shown below. No information was secured regarding the depths at which the samples were taken, but as the observer for the commission took a sample on June 29—the occasion of our visit to the gaging station—at mid depth it is presumed that the other samples were probably obtained at the same depth. The commission had quite a large number of samples that had been collected for several years back from which six were selected. Mr. Follett stated, however, that among these only samples taken May 7 and May 11, 1897, could be regarded as representing anything like a typical flow at time of high water. A sample that was taken September 23,1897, showed a larger amount of sediment than any other examined.

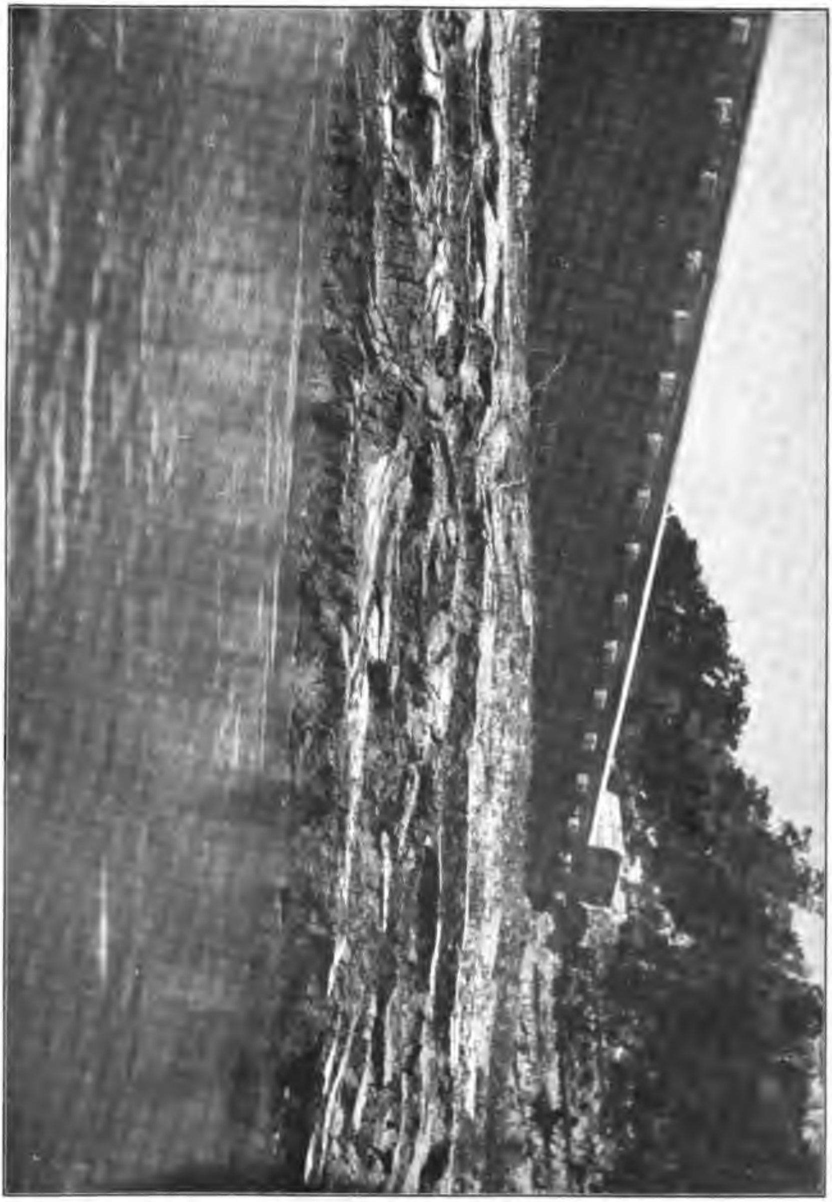
The silt in these samples seemed to be very finely divided during stages of considerable flow in the river, and the water did not become even moderately clear for several days, though all the silt proper—that is, all that portion that seemed to appreciably affect the quantity at the bottom of the tube—went down early in the settling process. The remainder seemed to be a flocculent substance that settled very slowly.

The following table gives the results of these determinations:

Silt determinations for the Rio Grande.

When collected.	Silt in water.						Discharge.	Total silt.	Time required to settle clear.	Remarks.
	Surface.	One-third depth	Mid-depth.	Two-thirds depth.	Bottom.	Mean.				
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*		
May 7, 1897	......	......	3.39	......	......	3.39	5,890	1.99	3.75 days.	Collected at gaging station, 4 miles above El Paso.
May 11, 1897	......	......	5.04	......	......	5.04	7,240	3.65	7 days...	Do.
July 8, 1897	......	......	9.79	......	......	9.79	980	.96	5.5 hours	Do.
Sept. 23, 1897	......	......	15.94	......	......	15.94	550	.87	5.25 hours	Do.
May 21, 1898	......	......	2.76	......	......	2.76	1,700	.47	4.5 days.	Do.
Nov. 8, 1898	......	......	1.52	......	......	1.52	1	....	....	Do.
June 27, 1900	......	......	.74	......	......	.74	95	.7	1.25 days	Collected at Lower Street Railway Bridge, El Paso.
June 29, 1900	......	......	.64	......	......	.64	45	.3	....	Collected at gaging station, 4 miles above El Paso.
July 23, 1899	26.25	26.25	......	27.25	25.63	26.34	(1)	....	....	Collected at Earlham Bridge; settled 30 days.
Aug. 13, 1899	33.75	33.75	......	33.13	34.37	33.75	(1)	....	....	Do.
Dec. 4, 1899	5.00	4.38	......	4.37	3.75	4.38	(1)	....	....	Do.
Do	3.75	3.75	......	3.75	3.75	3.75	(1)	....	....	Collected at Earlham Bridge; settled 30 days. Remeasured at end of 11 months.

[1] Mean not known.



REMNANT OF SILT ABOVE AUSTIN DAM.

Prof. Arthur Goss has reported determinations of percentages of silt in three samples of Rio Grande water collected at Earlham Bridge in 1899.[1] As already mentioned earlier in this article, Professor Goss allowed the samples to settle for thirty days, and it is for this length of settling that the percentages, as found by dividing the depth of silt by the depth that water stood in the tube when first poured in, are computed. The last sample, taken December 4, 1899, was allowed to stand for eleven months and remeasured, with the result shown on the last line in the table. The extra ten months resulted in a further subsidence of about 15 per cent of the volume as found at the end of thirty days. At the time of taking these samples the flow in the river was small, the stream having been less than 40 feet wide and 2 feet deep. Professor Goss states that at Earlham Bridge there has been little or no flow with the exception of the occasions on which these samples were collected.

In the summer of 1899 measurements were made of the quantity of silt carried by the water of this river by Mr. Follett. In making the silt measurements it was assumed that a cubic foot of dried sediment would weigh 85 pounds, the percentages being determined by weighing the dried sediment from a given amount of water. Between June 10 and July 28, 118 samples of water were collected from different parts of the river, and on the above assumption as to the weight of silt per cubic foot the average per cent of silt, when compared with the volume of water by which it was carried, was calculated to be 0.345. It is stated that the results varied from one-fourth to one-half per cent, except for the case of a flood of twelve hours' duration, due to local rains, when the silt amounted to 1.5 per cent.

Silt determinations were also made by the United States Geological Survey at El Paso during June, July, and December of 1889, and from January to August, inclusive, 1890, the percentage of sediment being determined by weight also, but in this case on the assumption that a cubic foot of dried silt weighed 100 pounds. The highest monthly percentage was found to be, on this assumption, 0.813 per cent in December, 1889, and the lowest, 0.131 per cent for July, 1890. From the results of the more recent silt measurements reported above it would seem that when determined volumetrically the percentage is much higher than this. Either the assumed weight per cubic foot—100 pounds—is too high or there is no direct relation between the volume and the weight. Finely divided silt would naturally be expected to have a somewhat different weight per unit of volume than would the coarser particles brought down by heavy floods. When resting at the bottom of a reservoir much water is contained in the pores of the silt, and while a cubic foot of dried sediment might weigh 100 pounds, the same amount of sediment would occupy a much larger volume within the body of the reservoir. For an ocular proof of this, note the shrinkage cracks in the sediment behind the broken Austin dam, as shown in Pl. XX. As this sediment had

[1] New Mexico Station Bul. 34.

been accumulating for fully seven years, one would expect it to be pretty thoroughly compacted. Nevertheless this was not the case—at least, a large amount of water was present, which on evaporating caused the sediment to shrink very much.

PECOS RIVER.

On July 6, 1900, the writer secured two samples of water from Pecos River, taking them at the crossing of the Texas and Pacific Railway, about 1 mile east of Pecos City. One sample was from the top and one from the bottom when the river was about 4 feet deep. On July 3 and 4 there had been heavy rains along the Pecos Valley, but when the writer left Carlsbad, N. Mex., on the morning of July 6, the river at that point was perfectly clear. Reaching Pecos City, however, he found that the rains below Carlsbad had caused the river to rise, and at the time of taking the sample it was still rising. No discharge measurement was made, however.

The percentage of silt in the surface sample was, at the end of a week's settling, 0.424, and in the bottom sample, 0.432. In spite of this rather small percentage the water looked very red and muddy. The silt was coarse and the water cleared in four hours on standing in the tubes.

Professor Goss has made a number of analyses of water from Pecos River.[1] He states that the amount of silt was too small to measure in tubes, hence the necessity of measuring it by the gravimetric method.[2] The percentage of sediment in water is very much less when the weight of dried sediment is compared with the weight of the carrying water than when the percentage is determined by volumetric measurements, so that the results for the Pecos water, as given by Professor Goss in the bulletin referred to above, can not be compared with the results for other streams unless the ratio of percentage by volume to percentage by weight be determined. It will be of interest, however, to observe how the amount of silt at different depths varies when computed by the ratio of weight of silt to the weight of the carrying water. Professor Goss gives the following results for six sets of samples taken by W. M. Reed, at Carlsbad, N. Mex.[2]

Silt carried by Pecos River at different depths.

When collected.	Surface.	One-third depth.	Two-thirds depth.	Bottom.	Mean.	Condition of river.	
						Width.	Depth.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Feet.*	*Feet.*
July 5, 1899	0.118	[3] 0.100	0.090	0.092	0.100	75	2.5
August 1, 1899	.3961	.4145	.435	.4176	.416	100	3.0
September 15, 1899	.0507	.0572	.0471	.0429	.0495	60	3.0
October 1, 1899	.0155	.0217	.0139	.0236	.0187	50	3.0
October 19, 1899	.0189	.017	.0146	.0218	.0181	([4])	([4])
December 1, 1899	.2925	.3238	.3040	.3373	.3144	([4])	([4])
Mean	.1486	.1557	.1508	.1559	.1528	....	....

[1] New Mexico Station Bul. 34.
[2] Private correspondence.
[3] Estimated; record lost. The mean given for the one-third depth is based on the assumption that the last sample in the first set would have yielded 0.1 per cent of silt.
[4] Not given.

CHEMICAL ANALYSES.

SEDIMENT.

Late in the summer of 1899, by an arrangement with Mr. H. H. Harrington, professor of chemistry in the Agricultural and Mechanical College of Texas, analyses were made of seven samples of the sediment derived from the waters of the Brazos and Wichita rivers, Mr. W. C. Martin, assistant chemist, doing the analytical work. On account of the small quantity of water taken in the samples, the potash could not be determined in the Brazos water, though it was in the water of the Wichita.

For comparison, the mean of 11 analyses reported by Professor Goss[1] are included in the table. Professor Goss's analyses are for sediment from the water flowing through the Las Cruces Ditch. This water had flowed through about 15 miles of ditch, in which the fall was slight, so that much of the sediment that the water had contained as it left the Rio Grande had been deposited before it reached the college, where the samples were taken.

The results of the analyses are given in the following table:

Analyses of sediment.

Constituents.	Parts in 100,000 parts of water.							
	Brazos River.[1]	Brazos River.[2]	Brazos River.[3]	Brazos River.[4]	Wichita River.[5]	Wichita River.[6]	Wichita River.[7]	Rio Grande. ([8])
Soluble matter (total solids) in filtered water	248.2	29.8	18.0	68.4	45.9	147.5	252.7	44.11
Suspended matter (silt) by volume[9]	4,520	2,080	730	1,020	4,400	5,480	2,300	....
Suspended matter (by weight)	2,310	1,230	190	270	1,220	2,670	630	831.4
Phosphoric acid, P_2O_5	15.8	17.9	8.4	17.9	17.9	19	14.1	139
Potash, K_2O	([10])	([10])	([10])	([10])	14.8	12	10.6	1,440
Nitrogen, N	15.4	15.0	....	....	7	7.7	6.7	108
Equivalent in ammonia, NH_3	18.7	18.1	....	....	7.7	8.4	7.4	....
Discharge in cubic feet per second	2,310	6,650	[11] 160,000	7,950	1,060	....	....	....

[1] Collected May 29, 1899; water red.
[2] Collected June 19, 1899; water turning from dark to red.
[3] Collected July 2, 1899; black rise; river 6 or 7 miles wide.
[4] Collected July 14, 1899; water red.
[5] Collected May 21, 1899; water red.
[6] Collected June 1, 1899; water very red.
[7] Collected from dam site: two sets of samples; collected June 8 and 19, 1899.
[8] Collected from Las Cruces Ditch, Mesilla Park, N. Mex. (See New Mexico Station Bul. 34.
[9] In Brazos and Wichita water sediment measured volumetrically at end of one week.
[10] Quantity insufficient for determination of K_2O.
[11] Estimated.

The first sample of Brazos water was heavily charged with sediment, and from its red color it was evident that it had come from the higher portions of the drainage area. The second sample was less heavily

[1] New Mexico Station Bul. 34.

charged, though containing much more than the average amount of silt. This water was just turning from dark to red, showing that the waters from the higher reaches of the river were beginning to mingle with the darker waters from the black-land regions. The total solids in the water was much lower in this case than in the former one. The third sample was taken at the time when the bottom lands were all overflowed, and the dark color of the water showed that the flood came mostly from the black lands of the State. In this sample the quantity of phosphoric acid was small, and the potash and nitrogen were not determinable in the small quantity of sediment used in the analyses. The same was true as regards the potash and nitrogen in the fourth sample, which was taken at a time when the quantity of silt was about normal. As one would expect, the percentages of potash and nitrogen in a given quantity of silt-containing water is higher when the percentage of silt is high, but the percentage of those elements in the silt alone decreases as the percentage of silt in the water increases.

The analyses of both silt and water show that usually the water that contains the smaller quantity of silt has the larger amount of total solids in the filtered water, though even in the few samples analyzed departures from this are apparent. Silt from the Las Cruces Ditch shows much higher percentages of nitrogen, phosphoric acid, and potash than do either the Brazos or the Wichita, when the waters are compared volume for volume.

Farmers along the Brazos regard a deposit of sediment—particularly if it be red sediment—as highly beneficial to the land, and the analyses show why this should be the case. The deposit from the Wichita, however, carries more plant food than does that from the Brazos, and both are far inferior in fertilizing value to Rio Grande sediment, as analyzed by Professor Goss. However, where water is stored most of this sediment would be deposited before reaching the land to be irrigated; so that no definite conclusions can be drawn from analyses of sediment in the river water unless it be known what proportion of this can be brought upon the land.

Both the Wichita and the Brazos deposit their sediment very quickly upon standing, and it is probable that but a small proportion of this would ever be utilized. With the Rio Grande—at least at some stages—the case may be different, as the sediment goes down more slowly. It would seem, therefore, that we should look to the water rather than to the sediment in deciding whether or not the application will enhance or depreciate the value of the lands to which it is applied. The compounds in solution in the water are sure to be absorbed by the soil, and, while some of them may be leached out again, others will continue to increase in quantity unless taken up by growing plants.

ANALYSES OF WATER.

Analyses were made of several composite samples, each made up of a mixture of several samples, all equal in volume except as otherwise noted, and all taken either at high or at low water. The object was to ascertain the difference in composition of waters containing much silt and those almost free from it. Analyses were made of two such composite samples from the Brazos and two from the Wichita. The results are given in the following table. Several quoted analyses are added to show the composition of Brazos and Wichita waters as compared with the waters of certain other streams.

The analyses of water from Las Cruces Ditch and part of those from the Pecos were made by Prof. Arthur Goss, and were reported in Bulletin No. 34, N. Mex. Exp. Sta. The volumes given for the Brazos and Wichita waters, by volumes, are for one week's settling, and should be reduced about 10 per cent when compared with the Rio Grande samples:

Analyses of water.

Constituents.	Parts per 100,000 parts of the water.									
	Brazos, No. 1.[1]	Brazos, No. 2.[1]	Wichita, No. 1.[2]	Wichita, No. 2.[2]	Las Cruces Ditch.[3]	Rio Grande.[4]	Rio Grande.[5]	Rio Grande.[6]	Pecos River.[7]	Pecos River.[8]
Suspended matter (silt), by volumes[9]	102	1,149	82	2,831	......	26,340	33.750	4,380	......	......
Suspended matter, by weight	......	303	......	1,357	831.4	10,780	12,396	1,147	179.6	122.5
Total solids	72.37	74.91	296.03	115.90	44.11	161.50	191.10	53.60	314.20	456.27
Lime, CaO	12.73	14.86	42.50	27.30	8.26	29.35	31.45	9.05	53.28	53.74
Soda, Na_2O	17.69	9.49	71.20	25.19	7.76	26.17	32.52	10.14	53.55	97.26
Potash, K_2O	.60	2.06	1.83	.63	.94	2.65	2.16	1.89	2.65	4.21
Sulphuric acid, SO_3	15	13.73	68.21	31.59	10.42	69.16	86.09	15.14	103.26	109.61
Chlorin, Cl	14.19	12.63	85.67	22.67	5.41	10.02	10.14	6.01	63.94	92.90
Phosphoric acid, P_2O_5	.51	.96	.21	Trace.	......	......	......	......	......	......
Magnesia, MgO[9]	......	......	......	......	1.36	6.38	7.05	2	17.08	......
Iron, aluminum, and silica (Fe_2O_3, Al_2O_3, SiO_2)	......	......	......	......	1.85	.50	1.02	.60	.93	......
Carbonates, CO_2	......	......	......	......	5.06	6.87	5.76	4.73	3.19	......
Crystal water and organic matter	......	......	......	......	4.27	12.66	17.20	5.40	29.16	86
Oxygen equivalent of chlorin	......	......	......	......	1.22	2.26	2.29	1.36	14.45	......
White alkali	......	......	......	......	22.09	82.73	101.25	29.51	157.38	......
Alkalis (as chlorids)	......	......	......	......	......	......	......	......	......	185
Total mineral matter	......	......	......	......	......	......	......	......	......	370.27
Total soluble matter	......	......	......	......	......	......	......	......	......	292.43
Total insoluble matter	......	......	......	......	......	......	......	......	......	163.84

[1] From Jones Bridge.
[2] From Wichita Falls.
[3] From Mesilla Park, N. Mex., average 1893-94.
[4] From Earlham Bridge, July 23, 1899.
[5] From Earlham Bridge, August 13, 1894.
[6] From Earlham Bridge, December 4, 1899.
[7] Average of six analyses.
[8] From Pecos City, Tex., 1899. Analysis by Mr. P. S. Tilson for the geological survey of Texas, December, 1889. The date of taking the sample is not given. The analysis was originally published by the Survey, but as the publication in which it appeared was not available to the writer, the figures here given were furnished by Mr. Tilson from his notebook.
[9] Magnesia, MgO, not determined in Brazos and Wichita samples.

The probable combination for the Brazos and Wichita waters is as follows:

Analyses of water.

Constituents.	Parts per 100,000 parts of the water.			
	Brazos No. 1.[1]	Brazos No. 2.[1]	Wichita No. 1.[2]	Wichita No. 2.[2]
Potassium chlorid, KCl	0.94	3.24	2.89	1.01
Sodium chlorid, NaCl	29.47	8.94	123.39	26.27
Sodium acid carbonate, $NaHCO_3$	14.00	17.30	15.63	....
Calcium sulphate, $CaSO_4$	25.50	21.76	85.86	38.44
Calcium acid carbonate, $CaH_2(CO_3)_2$	6.16	....	20.66	23.34
Calcic phosphate, $Ca(H_2PO_4)_2$	.84	1.57	.34	....
Calcium chlorid, CaCl	....	10.93	....	6.71
Magnesium sulphate, $MgSO_4$	....	1.29	26.57	....
Magnesium chlorid, MgCl	....	....	12.71	2.74
Sodium sulphate, Na_2SO_4	....	....	....	15.93

[1] From Jones Bridge. [2] From Wichita Falls.

The composite sample designated Brazos No. 1 was comparatively free from sediment and was made up of samples collected December 9, 1899, and January 2, March 3, and July 12 and 15, 1900. Brazos No. 2 contained a considerable red sediment and was made up of samples taken April 1 and 12, May 3, 6, 12, and 13, June 10, July 30, and August 5, 1900. The sample taken April 1 contained only one-half the amount of the other samples. The composite sample designated Wichita No. 1 was nearly clear and was made up of samples taken February 10, March 1 and 15, June 15, and July 1 and 15, 1900. Wichita No. 2 contained considerable sediment and was made up of samples taken June 7, 11, 12, 13, and 17 at 9 a. m., 2 p. m., and 4 p. m., 1899, and April 1, May 1 and 16, June 1, and July 19, 1900. No analyses of water from the Brazos at the time of a black rise was made.

It is noticeable that when the water is clear a much larger percentage of alkaline compound is carried than when the river is high. Indeed, at low stages it is possible to taste the salt in the water, this salty taste being much more noticeable in the Wichita than in the Brazos water. The analyses of the Brazos and Wichita waters were not complete, as it was not deemed necessary in the case of water to be used for irrigation. The magnesia was not determined, and where it appears under "The Probable Combinations for the Brazos and Wichita Waters" it was calculated to satisfy the remaining sulphuric acid and chlorin. The figures for magnesia sulphate and magnesia chlorid are, therefore, to be regarded as estimates.

The waters reported in the table as analyzed by Professor Goss were collected at Carlsbad, N. Mex., July 5, August 1, September 15, October 1, October 19, and December 1, 1899, together with one sample collected at Toyahvale, Tex., November 20, 1894. Professor Goss does not find black alkali in either the Pecos or Rio Grande waters.

While the number of analyses here given is not great enough to admit of drawing general conclusions, it is seen that the Brazos water

falls much below the Pecos water both in content of total solids and of alkali, and the same is true of the Wichita water taken at high stages of the river. In samples of clear water of the Wichita the total solids and alkali content run pretty high, but by reference to the table of daily discharges it will be seen that on days when these collections were made the river had but a small flow, while on the other hand the Wichita No. 2 samples were collected on days when the discharge was, in general, considerable. It would not seem, therefore, that the average composition of the water in a large impounding reservoir would be such as to prove very detrimental to growing crops, for the greater part of the water that would be stored would come at times when the river is high.

LARAMIE AND SALT RIVERS.

Silt determinations and analyses of water from Laramie River, made by Prof. E. E. Slosson, of the University of Wyoming, are given below. With the exception of the last two, the samples were taken at Woods Landing and at McGills. The former is on the Laramie, where the river crosses the Wyoming-Colorado line, running north. Volumetric determination of the quantity of silt present does not seem to have been attempted, due, no doubt, to its small amount. In comparison with the water of streams for which analyses have been given, the amount of alkali present is small, except in the two special collections made on July 8, 1899, at Holly, Colo., and at the headgate.

Analyses of water from the Laramie River at Woods Landing and McGills, etc.

Date of collecting.	Where collected.	Parts per 100,000 parts of the water.							
		Silt (insoluble).			Total dissolved.	Difficultly soluble (not alkali).	Alkali (easily soluble).	Sodium chlorid, NaCl.	Alkali not NaCl.
		From top.	From bottom.	Mean.					
1899.									
May 28	Woods Landing			5.08	8.40	3.35	5.05	1.85	3.70
	McGills			6.93	11.75	6.00	5.75	.80	4.95
June 15	Woods Landing	5.76	2.92	4.34	5.80	3.45	2.35	.55	1.80
	McGills	3.94	6.26	5.10	18.35	7.40	10.95	1.60	9.35
June 25	Woods Landing	2.17	2.33	2.25	7.00	4.90	2.10	.00	2.10
	McGills	4.22	3.17	3.70	7.15	3.90	3.25	.53	2.72
July 15	Woods Landing	1.48	1.81	1.65	8.25	3.95	4.30	.25	4.05
	McGills	3.46	6.25	4.86	17.50	8.70	8.80	.53	8.27
Aug. 1	Woods Landing	9.29	1.14	5.22	8.27	5.12	3.15	.26	2.89
July 25	McGills	1.10	3.95	2.53	15.28	6.23	9.05	.53	8.52
Aug. 15	Woods Landing	.72	.64	.68	11.50	7.70	3.80	.53	3.27
	McGills	.60	.95	.78	18.60	10.15	8.45	1.06	7.39
Aug. 25	Woods Landing	.23	.40	.32	17.72	13.54	4.18	2.25	1.93
	McGills	.86	6.34	3.60	22.60	10.48	12.12	.79	11.33
Sept. 15	Woods Landing	1.41	1.38	1.40	11.10	8.35	2.75	.66	2.09
	McGills	.69	1.75	1.22	29.20	13.90	15.30	1.33	13.97
Sept. 25	do	.51	1.75	1.13	32.32	15.17	17.15	1.06	16.09
Oct. 15	do	1.69	1.32	1.51	28.38	10.93	17.45	1.19	16.26
Oct. 30	Woods Landing	.09	.41	.25	14.75	7.45	6.30	.26	6.04
	McGills	1.75	1.72	1.74	28.47	14.15	14.32	.52	13.80
July 8	Holly, Colo			142.80	91.65	8.80	82.85	5.85	77
	Headgate			92.74	124.23	26.78	97.45	7.68	89.77
	Mean			13.17					

Results of some analytical determinations of silt in the waters of Salt River, Arizona, are given in the following table. These samples were taken by Mr. Diehl, and the determinations of silt were made by Prof. Robert H. Forbes, of the University of Arizona. These results have been converted from the units given by Professor Forbes to the units used in other parts of this report.

Analytical determinations of silt from Salt River water.

When collected.	Parts of silt per 100,000 parts of the water.	Remarks.
1899.		
May 15	7.67	From top and bottom.
May 25	6.01	
June 1	4.99	
June 7	7.41	
June 14	6.39	
June 15	5.06	Do.
June 21	6.13	
June 26	61.92	From top, after heavy rains.
Do	62.80	From bottom, after heavy rains.
June 28	21.74	
July 5	15.01	
July 12	39.85	
July 14	2,063.80	Top and bottom samples, after heavy rains in mountains.
Mean	179.14	

The table shows that, with the exception of the sample taken on July 14, the amounts of silt in the water are small. Inasmuch as the gravimetric determinations of silt seem to show always a much smaller proportion of silt to carrying water than do the volumetric determinations, the amount of silt in this last sample is really quite high. Any determination of silt is incomplete, however, unless the discharge of the stream at the time of sampling is known. In a marginal note opposite the results for the sample taken June 26, Professor Forbes states "4,000 inches in canal, after heavy rain." If this means that the sample was taken in an irrigation canal, it is probable that the proportions of silt in the river itself would have been higher than those shown in the table.

RAPIDITY OF SILTING UP OF CERTAIN RESERVOIRS.

In connection with these silt studies it will be helpful to examine into the rapidity of silting up of some reservoirs already constructed, and to describe some methods used in dealing with the silt question. With this end in view the author has visited a few reservoirs and the sites of some projected systems.

THE AUSTIN RESERVOIR.

The writer has no knowledge of any reservoir systems of any considerable magnitude that have been constructed in Texas for the

purpose of impounding storm waters for use in irrigation. Some interesting observations have, however, been made on the ill-fated Austin Reservoir, which was constructed for power purposes, but which should teach irrigation engineers some important lessons, not only in regard to reduction of storage capacity through deposition of silt, but also in regard to the selection of sites and the proper execution of the work from the engineer's point of view.

The Colorado dam at Austin, Tex.,[1] was completed in May, 1893. It was 68 feet in height and had a crest overfall of 1,091 feet. The reservoir was formed in a narrow gorge, and when the water was even with the crest of the dam, covered about 2,000 acres, the upper end of the reservoir being something like 25 miles above the dam. The original capacity was very nearly 51,800 acre-feet.

In May, 1897, four years after the reservoir was first filled, measurements showed that 38 per cent of the original capacity of the lake had been filled with silt. These measurements were repeated in February, 1900, and it was then found that the silt in the reservoir occupied 48 per cent of the original capacity. The rate of sedimentation for the first four years was therefore greater than for the whole time, or nearly seven years, about in the ratio of 100 to 74, notwithstanding that the amount of water passing during 1899 and 1900 was greater than during previous years. Indeed it may be that during these last two years the very fact that larger amounts of water were passing prevented the silt from settling as rapidly as when the flow was smaller, especially since the decrease in capacity of the lake would tend to produce a greater velocity within the long narrow reservoir.

The sediment was found not to be uniformly distributed over the bottom of the lake. Thus in February, 1900, the greatest deposit appeared to be at Santa Monica Springs, 13.7 miles above the dam, where 78.9 per cent of the original cross section had been filled with silt. The heavier particles of silt and the sand that may have been rolled along the bottom were deposited near the upper end of the reservoir, but the lighter particles were carried down and deposited all along, even well up against the back of the dam. In February, 1900, as much as 27 feet of silt had been deposited at one point behind the dam, where the original depth of water had been 66 feet. Toward the upper portions of the lake the deposits shifted with each rise, but it does not appear that this occurred anywhere near the dam.

April 7, 1900, after a very heavy rain, the water had reached a height of 11.07 feet above the crest of the dam, and the dam parted, wrecking the power house below and drowning several persons. The failure appears to have been due to the undermining of the founda-

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[1] The data for these statements are taken mostly from the columns of Engineering News, principally from communications from Mr. T. U. Taylor, professor of civil engineering in the University of Texas, at Austin.

tion at the toe, either by the water from the tailrace at the power house or by the water flowing over the crest, or by both.

When the dam broke, the great rush of water swept out the fine, impalpable silt, which for the most part seemed to resemble soft ooze, into which an oar could be thrust several feet, and left that portion of the lake next the east end of the dam almost clear of silt.

The photograph (Pl. XX, p. 310) taken by the writer June 21, 1900, shows the silt still remaining above the west end of the dam, where it had been somewhat protected from the current by the portion of the structure that remained standing. This photograph was taken from a boat, a short distance above the water surface, and therefore shows the silt in exaggerated proportions when compared with the height of the dam. At this time the depth from the crest of the dam to the top of the silt was about 39 feet, and as the axis of the stream had been close to this side of the lake it is probable that the maximum depth of 66 feet of water was near this point, thus leaving about 27 feet of silt even after the rush of the outgoing water had passed. The photograph shows crevices in the deposit due to drying out. Some of these crevices extended for many feet down into the mud, and even when seen by the writer a great portion of the surface would not bear a man's weight. Even at the time of the writer's visit, two and one-half months after the breaking of the dam, the water was still highly colored from the red silt that had been deposited in the lake basin. Above the head of the old lake the water was said to be perfectly clear, as it usually is at the low stage of the river that then existed.

It is estimated that there were 135,000 cubic feet per second flowing over the dam at the time of the break. This discharge would amount to nearly 267,800 acre-feet in twenty-four hours, or water enough to fill the lake five times over, if we consider its original capacity of 51,800 acre-feet. This assumes that the river would continue to discharge the same amount of water for twenty-four hours that it appears to have been discharging at the time the dam failed. Considering the large quantity of silt carried at flood water and the greatly reduced velocity of flow in the reservoir, it is easy to see why the rate of silting up should have been so high. In a reservoir system intended for irrigation purposes the relation between the discharge of the stream and the capacity of the reservoir should be such that the latter should be filled only a few times in the course of a year if situated on a stream carrying any considerable amount of silt; otherwise the deposition of silt would be rapid.

It may be remarked incidentally that, aside from the silt question, experience with the Colorado dam may point other morals for engineers. It has already been stated that the failure of the dam was probably due to undermining at the toe. At the time of the break the water had probably worked a passage through underneath the dam at the point where the failure first occurred, for soundings show

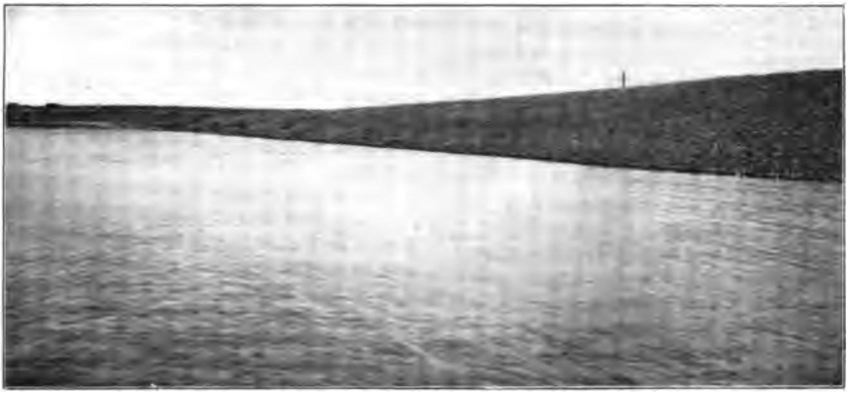

FIG. 1.—DAM AT LAKE MCMILLAN FROM UPPER SIDE.

FIG. 2.—LAKE AVALON DAM DURING CONSTRUCTION.

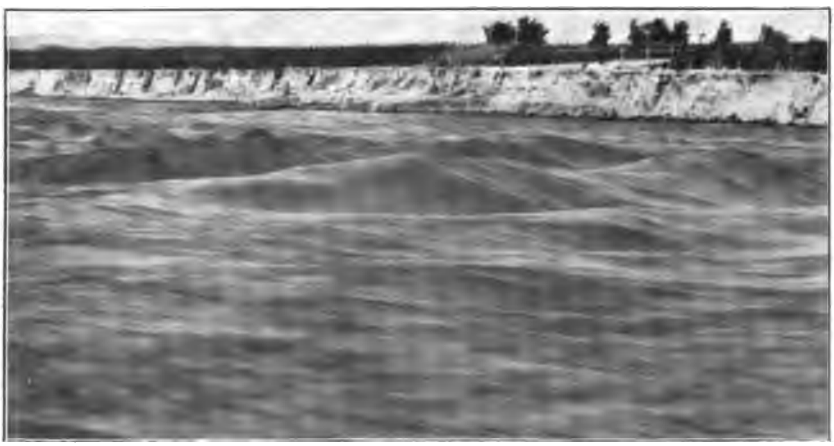

FIG. 3.—VIEW OF PECOS RIVER 1 MILE WEST OF CARLSBAD, N. MEX.

FIG. 1.—PORTION OF WASTE WEIR AT LAKE AVALON.

FIG. 2.—WASTE WEIR AT LAKE AVALON—GATES PARTLY OPEN.

FIG. 1.—WASTE WEIR AT LAKE AVALON.

FIG. 2.—SLUICE-GATE OUTLET IN BOTTOM OF OLD DAM AT LAKE AVALON.

that a portion of the bed rock had disappeared. The writer visited the site of the dam in June and saw one place near the headgates in which the water had worn away several inches of the limestone from beneath a granite block that had been set in cement on this rock. Small fragments of the limestone were still held to the block by the cement in which it had been set. The failure of this dam should teach a lesson on the importance of properly selecting the site for a large dam and of the necessity of adequately protecting the structure from excessive floods.

Again, in making plans for this dam, errors in placing the minimum discharge too high led to serious trouble in operating the power at the dam, for several times the water fell below the crest, so much so sometimes that it was necessary to cut off light and street-car service in order to maintain sufficient reserve power for the waterworks. This emphasizes the necessity for careful measurements of available supply before constructing costly works in which the amount of water available is a consideration, as it often is in irrigation as well as in questions relating to power plants.

PECOS RESERVOIRS.

Mr. W. M. Reed, special agent in irrigation investigations, Roswell, N. Mex., has made a few observations on the silting up of the two reservoirs of the Pecos Irrigation and Improvement Company at Carlsbad, on the Pecos River. The lower of these reservoirs, located 6 miles above Carlsbad, and known as Lake Avalon, is used as a distributing reservoir. The upper one, 9 miles farther up, is known as Lake McMillan, and is used as a storage reservoir. Lake Avalon was originally finished in 1890 and reconstructed after a failure in 1893. The dam is 1,380 feet long on top, and has a maximum height of 48 feet. The lake submerges 1,980 acres, its maximum width being 1½ miles and its total length 5 miles. Its capacity is given as 6,300 acre-feet. The cost of the dam and the headgates was, in round numbers, $165,000.

Lake McMillan was finished in 1893. The length of the dam (Pl. XXI, fig. 1) is 1,686 feet and its maximum height 52 feet. The length of the lake is 8½ miles, its greatest width 3½ miles, and the area submerged 8,331 acres. Its capacity is placed at a little less than 138,000 acre-feet. The total cost of the dam, headgates, etc., was $290,000 The irrigable area under the company's canals is 200,000 acres.

From Mr. Reed it has been learned that prior to the building of Lake McMillan there was some sediment deposited in Lake Avalon. This sediment was said to average about 3 feet in depth in 1893. If the capacity of Lake Avalon is only 6,300 acre-feet, as stated, this would indicate that a large part of the available capacity has been lost. Since the construction of Lake McMillan, Lake Avalon has not

silted up to any appreciable extent, the silt being caught in the upper lake.

The water in Lake McMillan having got quite low in 1899, Mr. Reed made some investigations on the deposit of silt in this lake over the exposed portions, using a shovel to determine the depth of silt. He found that the depth increased from the dam toward the upper end. Near the dam it was about 16 inches, while near the upper end it was as much as 4 feet. Since the Pecos was quite low all through 1899 it is not probable that much silting up occurred during that year.

METHODS OF DEALING WITH THE SILT PROBLEM.

The author has made inquiries, so far as opportunity has been offered, concerning the methods of dealing with silt in reservoirs already constructed in cases where the silt question arises. The results of this inquiry are presented herewith.

METHODS OF DEALING WITH SILT IN CANALS ON THE PLATTE RIVER, IN NEBRASKA.

Mr. C. B. Channel, State engineer of Nebraska and secretary of the State board of irrigation, has furnished the writer with descriptions of two small power and irrigation systems taking water from the Platte River, in Nebraska, and of the methods of dealing with silt there employed. The great difficulty in diverting water from the Platte River is to exclude the sand that continually rolls along the bed of the stream.

One of these systems (the Gothenburg system) was constructed in 1890 for the purpose of obtaining water power at Gothenburg, Nebr. Water is conveyed into a reservoir near the town from the river 9 miles above. In constructing the canal several small ponds or lakes were formed between the headgates and the reservoir by building dams across ravines, and in these much of the silt carried into the canal has been deposited. There have been no surveys made on these ponds or reservoirs from which an estimate of the amount of silt deposited can be made. Several of the smaller ponds have been filled with silt to the grade line of the canal. This filling up was hastened by dredging operations above the ponds, which greatly increased the amount of silt carried in the water.

The other system, the Kearney Canal and Reservoir, was constructed to furnish water power at Kearney, Nebr. The water is diverted from the Platte River by a wing dam about 16½ miles west of the city of Kearney. The amount of silt or sand carried in suspension is not sufficient to cause much annoyance, or at least has not done so up to the present time. When the water is diverted from the river into a canal, and the velocity thereby reduced, the sand is deposited near the head of the canal, and it is necessary to take it out either by means of teams and scrapers or to have sluice gates, when conditions are favorable, to wash the sand back into the river.

PECOS FLUME.

FIG. 1.—RESERVOIR AT GOTHENBURG NEBR.

FIG. 2.—WASTE WEIR OF RESERVOIR, KEARNEY, NEBR.

SUGGESTED METHODS OF DEALING WITH SILT IN THE PROPOSED RESERVOIR ON WICHITA RIVER.

Surveys were made in 1897 by Murray Harris, civil engineer, in the interests of the Wichita Valley Irrigation Company for an irrigation system on Wichita River, in which it was proposed to dam the river at a point in Baylor County about 35 or 40 miles above Wichita Falls, and to bring water down the valley, irrigating lands on both sides of the river to the extent of something like 200,000 acres. It was estimated that there are 270,000 acres that could be reached by the system, and it was also estimated that 1 acre-foot per acre would be sufficient water for the ordinary season, which is such that only a small portion of the water required elsewhere need here be supplied by irrigation. The people who were interested in the proposed system were confident that one or two irrigations annually would suffice for many crops. As the reservoir was designed to contain about 200,000 acre-feet of water there would be sufficient water at one filling to answer for a season's use. It is probable, however, that the reservoir will be filled at least twice during the season, so that if more than a depth of 12 inches is needed it can probably be supplied without difficulty.

The cost of the reservoir complete was estimated by one engineer to be $900,000, and of the entire system to be $1,708,000. Another engineer estimated the cost at a considerably lower figure.

The advantages that this proposed system has over the majority of systems are many, not the least of which is that the region already has an excellent agricultural population, so that one of the most serious drawbacks to the successful operation of an irrigation system—the lack of men at hand to till the soil—would not be felt. The Wichita Valley and lands adjacent thereto are among the most fertile in the State, as is shown by the splendid crops that have been produced in good seasons. During 1900 the average wheat crop was something like 20 bushels per acre, with many instances of 24 bushels or more per acre. A great variety of crops can be grown. While the rainfall is not uniform enough to always insure good crops, it is sufficient to place the region almost, if not quite, within the semihumid region, so that much less water will be needed to insure good crops than is needed in the regions of the West where irrigation is now extensively practiced.

The most serious danger that has threatened the scheme has been the fact that at flood tide the water is so heavily charged with silt that it was feared that the reservoir would be filled to such an extent that its storage capacity would be greatly reduced before the results obtained would have justified the great outlay that would be necessary for its construction. That there is danger from this source is evident from the quantity of silt carried in the water at times of high water, as is shown by the table of silt measurements on this river (p. 308). However, it was shown in the course of these investigations that even in the present year, in which the flow of the river was

larger than usual, the average percentage of silt in the water when reduced to its probable volume at the end of one year is less than 1 per cent. By having the outlet tunnel of the reservoir open during periods of high water it would seem possible to maintain somewhat of a current throughout the body of the reservoir, so that excessive precipitation of silt would probably not occur. This outlet would not suffice, however, to flush out silt when once it had been deposited and become well settled. If, however, by some such means as keeping the outlet tunnel open during periods of high water the reservoir could be kept from rapidly silting up, there would seem to be no reason why such a reservoir should not serve its purpose long after the results obtained would have repaid the cost of its construction.

Cheap settling basins might be constructed above the reservoir to catch the excessive silt, or the dam might be raised as required, thus increasing the storage room, and in this way the diminution of capacity due to silt deposit be made good.

SUGGESTED METHOD OF DEALING WITH SILT IN THE PROJECTED ELEPHANT BUTTE RESERVOIR.

A company was organized in 1893 to construct a dam at Elephant Butte, about 112 miles above El Paso, from which it was proposed to irrigate a large area in New Mexico and Texas. The dam was designed to be 96 feet high and 550 feet long on the crest. The estimated capacity of the proposed reservoir was 253,000 acre-feet, its length 16 miles, its greatest width 2 miles, and its greatest depth 75 feet. The canals were intended to extend down the Rio Grande Valley to a point about 90 miles below El Paso, and the area in the valley proper that could be reached by these canals was estimated at 230,000 acres, besides 950,000 acres of mesa land under a high-line canal. The estimated cost of the main dam, two diverting dams, and the distributing canals to the lower end of the Mesilla Valley was $659,020.

No provision was made for the disposition of the silt that would accumulate in the reservoir, but a partial remedy existed in the fact that an auxiliary reservoir of about 175,000 acre-feet capacity would be constructed in the valley immediately above the storage reservoir and would serve as a settling basin. This basin would occupy a narrow, rugged portion of the valley that is without value for irrigation purposes. It is stated that silt that has once been deposited in such a large reservoir can not be afterwards removed. In connection with the project at Elephant Butte the silt problem is the most serious one to be met.

The company that had projected this dam was restrained from constructing it by legal proceedings instituted by the United States Government at the instance of citizens of Juarez, Mexico, and on the ground that it would render a proposed international dam at El Paso useless.

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